Organizational Results Research Report

September 2005
RI01.007

Development and Implementation of Environmental Roadside Inventory

Prepared by
Missouri Department of Transportation

FINAL REPORT

RI01-007

Development and Implementation of Environmental Roadside Inventory

Prepared for the
Missouri Department of Transportation
Organizational Results Division

by
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16. Abstract

With the advance of global positioning technology (GPS) and geographic information systems (GIS), the roadside and roadway maintenance staff at the Missouri Department of Transportation (MoDOT) wanted to investigate their use in both roadside and roadway asset management. Researchers envisioned a computer map that would show detailed information about roadside vegetation and roadway features with just the click of a mouse. It was also suggested that the map might be used to track the effectiveness of current vegetation management practices on a single species or group of species.

This research project was launched to develop and evaluate this technology at MoDOT. This project included: 1) mapping of both native and invasive species of interest to establish baseline population parameters, 2) mapping of areas on the right of way for potential native vegetation establishment, and 3) mapping of roadway maintenance features for asset management. Mapping of native species focused on showing the boundaries of prairie remnants along with identifying and mapping selected species within the boundaries of the remnants. Re-mapping selected species at the same location over several seasons collected population dynamics from year to year. Mapping the same species at other locations provided data to compare dynamics between populations. Techniques and processes were developed to use GPS in collecting data on spatial and attribute data for both environmental and man-made features for import into a GIS. Templates for pictorial maps and tables were also developed within a GIS.

Both technologies proved to be efficient and effective methods for collecting and analyzing natural and man-made roadway features. The pictorial map format provided an added benefit of allowing viewers to see spatial relationships between various features. Viewers were able to associate the attributes of each feature in a spatial context. This is a sharp contrast with handwriting the information in a notebook or entering it into a spreadsheet on a handheld computer. The result is a powerful tool to make vegetation or roadway management decisions. Further implementation of this technology will result in more targeted and accurate roadside operations, which in turn can reduce the associated risks. In addition, costs for vegetation management can also be reduced with less herbicide used to achieve the desired effect. The goal of any operation at MoDOT should be to achieve the desired result in the safest, most cost efficient manner. The results of this study show that GPS/GIS technology can be a powerful tool to achieve this goal.

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Executive Summary

Remember the puzzle of the United States you put together as a child? Or maybe you remember a tourism map from a family vacation. The most interesting ones had more than just the roads you traveled. They also had symbols and images of historical sites or other points of interest. You may even remember watching for a giant sunflower as you crossed into Kansas or an oversized statue of Lincoln in Illinois. With the advance of global positioning technology (GPS) and geographic information systems (GIS), the roadside and roadway maintenance staff at the Missouri Department of Transportation (MoDOT) wanted to know if a similar map could be made for their use. Researchers envisioned a computer map that would show detailed information about roadside vegetation and roadway features with just the click of a mouse. It was also suggested that the map might be used to track the effectiveness of current vegetation management practices on a single species or group of species.

This research project was launched to develop and evaluate this technology at MoDOT. This project included: 1) mapping of both native and invasive species of interest to establish baseline population parameters, 2) mapping of areas on the right of way for potential native vegetation establishment, and 3) mapping of roadway maintenance features for asset management. Mapping of native species focused on showing the boundaries of prairie remnants along with identifying and mapping selected species within the boundaries of the remnants. Re-mapping selected species at the same location over several seasons collected population dynamics from year to year. Mapping the same species at other locations provided data to compare dynamics between populations. Techniques and processes were developed to use GPS in collecting data on spatial and attribute data for both environmental and man-made features for import into a GIS. Templates for pictorial maps and tables were also developed within a GIS.

Both technologies proved to be efficient and effective methods for collecting and analyzing natural and man-made roadway features. The pictorial map format provided an added benefit of allowing viewers to see spatial relationships between various features. Viewers were able to associate the attributes of each feature in a spatial context. This is a sharp contrast with handwriting the information in a notebook or entering it into a spreadsheet on a handheld computer. The result is a powerful tool to make vegetation or roadway management decisions.

Further implementation of this technology will result in more targeted and accurate roadside operations, which in turn can reduce the associated risks. In addition, costs for vegetation management can also be reduced with less herbicide used to achieve the desired effect. The goal of any operation at MoDOT should be to achieve the desired result in the safest, most cost efficient manner. The results of this study show that GPS/GIS technology can be a powerful tool to achieve this goal.

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Introduction

The Missouri Department of Transportation (MoDOT) investigated the use of global positioning systems (GPS) and geographic information systems (GIS) for conducting inventories of both environmental roadside features (vegetation) as well as man-made roadway features. The purpose of this study is two-fold. First, MoDOT wanted to evaluate the utility of this technology for integrated vegetation management by cataloging the locations of species of interest and entering this data into a GIS. Subsequent mapping can serve to track the effects of current vegetation management practices on each species or group of species. Secondly, MoDOT maintenance personnel wanted a spatially accurate database of roadway features that would be compatible with the existing TMS software and that would be user-friendly.

The Missouri Department of Transportation's (MoDOT's) roadside management philosophy is to preserve, enhance, and diversify the roadsides of Missouri's transportation system. A major part of this is the identification and preservation of native vegetation on MoDOT right-of-way, as well as the identification and elimination of invasive and noxious weed species. Based on the observations of MoDOT's vegetation managers, botanists from public and private organizations, and native vegetation enthusiasts, MoDOT's 385,000 acres of right-of-way throughout the state contain many areas that are dominated by beneficial native prairie vegetation. Unfortunately, we also know that invasive weed species are present on our rights-of-way and these species appear to be spreading. To date, there has been no major effort to document the locations, species compositions, or size of either the native vegetation remnants or the areas infested with weeds. Therefore, MoDOT has not been able to efficiently preserve the natives or understand and control the spread of invasive weeds. To solve this problem, this study examined the use of GPS to identify prairie remnants and individual plant species (both native and invasive), and then integrate these data into a GIS.

The use of GPS and GIS technologies in natural resource management became widespread during the 1990's as local, state, and federal resource agencies recognized that spatially oriented data can be powerful tools to find patterns and relationships that may be overlooked with traditional data sets. For example, in Florida, researchers at the University of Florida have been using GIS to identify landscape features that could be incorporated into an ecological greenways network (Carr et al. 1998). Additionally, the Florida Division of Recreation and Parks has used GIS for vegetation management, habitat restoration, environmental damage assessments, and endangered species mapping and monitoring. The U.S. Forest Service has used spatially oriented vegetation maps of public lands to locate optimal habitat for threatened and endangered species. The World Resources Institute (WRI) has used GIS data and maps to study worldwide deforestation and has identified threats to frontier forests (Lang, 2000). The concepts developed by WRI can be applied on a regional level when looking at stands of native vegetation on roadsides, and identifying threats to their survival. In Clinton County, Iowa, roadside vegetation managers have integrated data about the locations of native vegetation into the on-board computer systems of high-tech herbicide application equipment (Marum, 2000).

GPS and GIS are used successfully in MoDOT environmental work, survey crews, and transportation planning. Environmental Studies personnel in Design at General Headquarters currently use GIS/GPS technology to map and integrate information about wetlands, endangered species, and cultural resources. The successful use of this technology for natural resource management at MoDOT prompted us to develop the hypothesis that this technology could be used to successfully manage yet another of our natural resources - roadside vegetation. Prior to planning this research project, MoDOT was already beginning to see the potential benefits of this technology for roadside vegetation management. The agricultural industry had been using GPS and GIS successfully since the mid-1990's and it was not long before equipment manufacturers began to realize that agricultural field applications had direct correlations to roadside applications. MoDOT purchased several GPS-equipped herbicide injection spray units similar to those being used by Clinton County, Iowa, and located them in districts 3, 4, and 8. These trucks can be used to map areas of herbicide application and areas that are sensitive to these applications. Initial use of the GIS/GPS technology on the trucks was limited. In order to utilize this equipment more effectively, data and direction needed to be provided. Use of GIS/GPS technology to aid in vegetation management practices had not previously been attempted in Missouri.

Data management and reporting will increase in the near future. By giving data a spatial reference, each piece of information is provided with a context and therefore a new method of analysis. GIS provides “proximity analysis” which in turn provides answers to geographically complex questions in a way that can easily be used. “In providing once esoteric or cryptic information with a visual explanation, technological expertise among system users fades as an issue” (Steele, 2000). GPS is often used to fill in information gaps and once a GIS is in place, it remains a tool for data maintenance and enhancement. The city of Everett, Washington’s Public Works Department has integrated its databases into a central management system that incorporates GIS technology. The result has been better tracking and asset management saving taxpayers’ money (Brandley, 2001). Camden County, New Jersey uses a GIS-based asset management system to keep track of its roadway signage and signals. The system allows the county to track the history, maintenance, inventory, and management of signs and signals. They system can also be used for other infrastructure items such as roadways, pavement segments, bridges, lights, and water and sewer components. The GIS has provided the county with timely and accurate information to support decision-making (Noe, 2000).

The successful use of GPS/GIS technology by others in the fields of natural resource and asset management illustrate that it would be advantageous for MoDOT to explore its use for similar purposes. This study seeks to do just that by examining its potential to inventory both roadside environmental features and roadway features. Both sets of features have important implications for MoDOT maintenance forces. Successful management of these resources saves taxpayer dollars and illustrates MoDOT’s commitment to managing its resources.

Objectives

In this study, we seek to develop both an environmental roadside inventory and a roadway features inventory using GPS and GIS technologies. The environmental roadside inventory will be incorporated into the district roadside management plan. A spatially accurate roadside vegetation inventory will be created through GPS data recording in several locations throughout the district. Special emphasis will be placed on native prairie remnants and areas of noxious weed infestations within MoDOT rights-of-way in order to develop a more comprehensive and responsible roadside vegetation management plan for these areas. The information collected will be incorporated into a GIS system and will then be used to develop mowing, herbicide and vegetation management strategies for the corridors. The resulting database will also prove valuable for identifying and managing possible environmental impacts associated with route improvements in the future. The roadway features inventory will be used to inventory the location and attributes of various man-made roadway features.

The components of the study, their locations (Figure 1), and the objectives of each are summarized as follows:

1) Route 36 Corridor – A 36-mile stretch of highway between Route J, Ralls County, to Clarence, Shelby County that contains many native prairie species. The objectives were to determine how many acres of prairie remnant occur on right-of-way in this area, determine the species composition within the corridor, record the presence of any rare or endangered species, examine the status of noxious or invasive weeds in the corridor, examine population trends of selected species over multiple growing seasons, and examine correlations between locations of prairie remnant within the corridor and surrounding land usage.

2) Route 61 Corridor – A 30-mile stretch of highway in Pike County, south of Frankford to Eolia that contains large amounts of common teasel, cut-leaf teasel, and musk thistle - three species of noxious weeds that are spreading rapidly in northeast Missouri. The objectives were to determine the acreage of infestation of each species, the relative density of infestation within each patch of plants, examine population trends over multiple seasons, and incorporate data collected into a management plan to control these species.

3) Route 54 Corridor – 4.5 miles east and west of Vandalia, Audrain County, that contains many native prairie species. The objectives were to record the abundance of pale purple coneflower and eastern gama grass within the corridor in order to establish a baseline population of each for comparison with future mapping sessions and with other populations.

4) Route Z Lincoln County Area – This is a small area along the south side of Route Z in Lincoln County that contains a large number of interesting and uncommon prairie species. The objective for this area was to map the population of pale purple coneflower in order to establish a baseline population of each for comparison with future mapping sessions and with other populations.

5) Native Wildflower and Grass Seeding Conversion Sites – A cooperative project between MoDOT and MDC involving conversion of areas along MoDOT rights-of-way from weeds and fescue to native grasses and wildflowers. The objective for this project was to map and record the acreage of each site to be converted for inclusion in bid packets for contractors wishing to perform the seeding.

6) Roadway Features Inventory – This portion of the project occurred within the Route 36 corridor and involved mapping and displaying within a GIS man-made roadway features such as signs, culverts, etc. The objectives were to 1) establish a process to inventory and map relevant roadway/maintenance features similar to the process being developed for the environmental roadside inventory, 2) identify additional maintenance and environmental features to be included in a state-of-the-art GPS/GIS inventory of MoDOT roadways, 3) Increase awareness and use of GIS/GPS at MoDOT, and 4) investigate and pursue integration of roadway features data into department's TMS system.

The techniques, data, and implementation experiences resulting from this project will be shared with roadside managers across the state. Other districts can then benefit from the experiences in District 3 in establishing their GIS-based roadside vegetation and roadway features management strategies.

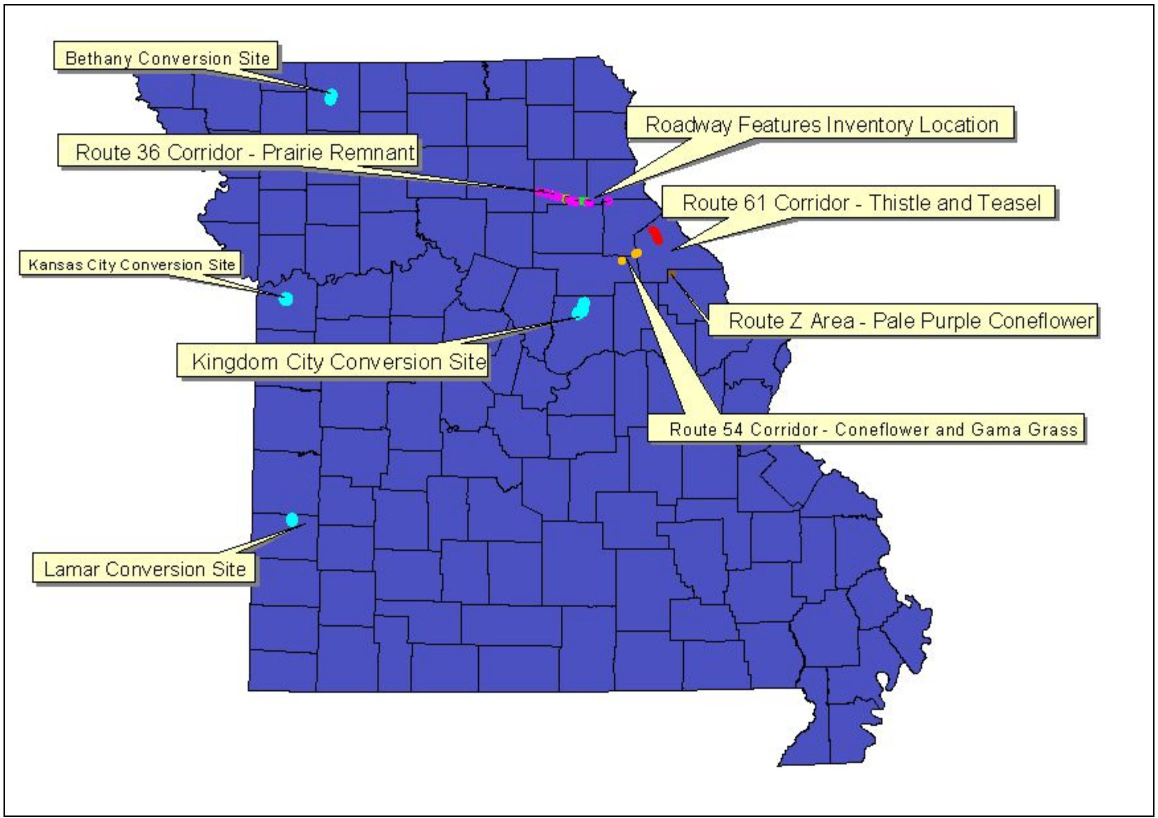

Figure 1: Map illustrating the locations for the various components of the study.

Discussion of Present Conditions

Environmental and management concerns for roadside maintenance include such issues as the use of herbicides, cost and frequency of mowing, hydrology, invasive plant species, and the restoration and preservation of native plants and animals. The use of GIS/GPS in roadside vegetation management can be a very powerful tool for gathering data about areas of concern such as noxious weed infestations, disease or pest outbreaks, and areas sensitive to mowing or herbicide applications. MoDOT's herbicide and mowing practices can be refined with an environmental roadside inventory. Identification of grass species and their locations allow more prudent herbicide applications, reduced mowing costs in areas of certain types of natural vegetation, and overall better management of the right of way. We currently have no efficient or accurate methods of keeping track of our roadside vegetation. Roadside vegetation information developed through GPS field coding and GIS application will allow roadside managers and other MoDOT decision makers to better manage roadside appearance while making informed decisions about mowing and herbicide use.

Management concerns for roadway maintenance include the location of signs, drainage structures, guardrail, and other assets along with their associated attributes. Keeping track of these assets and their condition is the responsibility of local maintenance personnel who periodically check the condition of these features and replace or repair them as necessary. A sign log documents the locations of various types of signs and their locations. MoDOT's TMS database also stores information on the location and conditions of various MoDOT assets. However, there is no easy-to-use tool that keeps track of all of the roadway features important to maintenance personnel that allows them to easily add field collected data and display it in map format. Field collected data using GPS to record the location of maintenance features and their attributes and then incorporating them into a GIS to display them spatially can result in more efficient asset management.

The use of GIS/GPS technology in field operations at MoDOT can enhance the overall effectiveness of our workforce. Use of this tool in field operations will allow for better management decision-making. Establishing a roadside vegetation inventory demonstrates to other agencies MoDOT's commitment to environmental stewardship, and the development of a roadway features inventory demonstrates MoDOT's commitment to efficient management of its maintenance assets. Both are important to the taxpayers of Missouri who deserve no less than good environmental stewardship and efficient use of their money by MoDOT.

Technical Approach

Equipment used for the study included a Trimble Pro-XR GPS with TSC1 Data Logger for data collection in the field. The GIS was a Compaq Professional Workstation AP250 minitower loaded with Pathfinder Office and ArcView 3.2a GIS software and equipped with a Hewlett Packard CD-Writer 9600se and an Iomega 250 megabite external zip drive. Photos of plants were taken with a Kodak DC290 digital camera.

Route 36 Corridor

During August 2001, all prairie remnants within the Hwy 36 study corridor were identified based on visual assessment of vegetation. For an area to be classified as prairie remnant, the majority of vegetation observed in the area had to be native non-woody. Large areas of fescue with a few isolated pockets of native vegetation were not considered prairie remnant. Since all of the prairie remnants studied are linear in nature, most remnants were divided into 200-foot long sections. Some were divided into quarter mile sections. Each section was mapped with the Trimble GPS receiver by walking around the perimeter of the remnant. The operator of the GPS unit would record the boundaries of each section and classify each as prairie remnant.

During late spring and summer of 2002, the distribution of 26 species of native forbs and two species of non-native noxious weeds were mapped throughout the Hwy 36 study corridor. Noxious weeds are plant species that are mandated by state law to be controlled due to their invasiveness. Species selected for mapping were chosen based on their implications to MoDOT vegetation managers. Individual plants were mapped as single points where numbers of individuals were small and scattered. In instances where large patches of individual species occurred, the perimeter of the patch was mapped. Individual plants within the patch were counted in order to determine the density within the patch. In instances where individual plants or populations exhibited characteristics of interest to vegetation managers, additional data were recorded [e.g., evidence of digging in the case of pale purple coneflower (*Echinacea pallida*), or herbicide damage on indigo bush (*Amorpha fruticosa*)]. In addition to mapping individuals and patches, in instances where species were so common throughout each section of remnant that they could not be easily mapped, we recorded that species as dominant in that section. Recording of dominant species for each section was performed three times throughout the summers of 2002 and 2003. Observations were for blooming plants during mid-June, mid-July, and mid-August. In 2004, observations were only made for mid-June and mid-July. Thus, we recorded dominant blooming species in each section of prairie remnant at these times and added these data to the mapping data. After each session of data collection in the field, the information stored on the GPS data logger was transferred to the GIS workstation. We used 7.5 minute USGS Digital Orthophoto Quarter-Quadrangles (DOQQ's) in geotiff image format for basemaps. All data concerning plant locations was overlaid using the DOQQ's in order to create maps showing the locations of each individual plant or patch. Dominant blooming species data for each section of prairie remnant were entered into separate databases for each section of remnant. These databases were "hot-linked" for each section of remnant depicted on the map so that when each remnant section was selected, the associated database would appear.

Route 61 Corridor

Noxious weed species mapping within the Hwy 61 study corridor began in 2003 and continued into 2004. Species examined were common teasel (*Dipsacus fullonum*), cut-leaf teasel (*Dipsacus laciniatus*), and musk thistle (*Carduus nutans*). Due to the large number of plants within a patch, individuals were not counted. Mapping consisted of walking the perimeter of each patch and recording the level of infestation within the patch as high, moderate, or low density. In areas where these species were scattered, individual plants were mapped. Field-collected data were incorporated into a GIS and DOQQ's were again used as base maps.

Route 54 Corridor and Route Z Area

These areas were mapped during June 2004. Mapping focused on pale purple coneflower at both locations and eastern gama grass (*Tripsacum dactyloides*) at the Route 54 locations. Individual plants and patches were mapped and entered into a GIS.

Native Conversion Projects

Four locations within MoDOT right-of-way throughout Missouri were selected by MoDOT and MDC personnel to convert to native prairie wildflowers and grasses. We visited the sites and mapped a square within each proposed conversion plot. This data was entered into a GIS, overlaid on DOQQ's, and the boundaries of each mapped square were stretched within the GIS to conform to the proposed boundaries of each conversion plot. Thus, the boundaries were defined within the GIS rather than walking the perimeter of each proposed plot in order to save time in the field. The proposed plots were outlined within the GIS, maps were produced to scale, and the acreage of each plot was calculated within the GIS. This data, along with the maps, were provided to MDC personnel as well as Roadside Operations personnel at the Central Office to be included in bid packets for contactors wishing to bid on the project.

Roadway Features Inventory

A 10-mile section of roadway within the Route 36 Corridor from west of Monroe City to Route J, Ralls County, was selected as a test for the roadway features inventory. The following features were selected to be mapped and included in the GIS: signs, underground utilities, driveways, concrete box culverts, state and county roads, shoulder and pavement changes, and no passing zones. The locations of each of these features, as well as information about each feature, was recorded in the field and then included in a GIS. Data were overlaid on DOQQ's and displayed in map format within the GIS.

Results and Discussion

Route 36 Corridor

A total of 50 acres of prairie remnant were identified and mapped within the Hwy 36 project corridor during the summer of 2001. During 2002, a total of 33,121 plants were mapped within this corridor (Table 1). Twenty-six prairie indicator species were mapped, along with two species of non-native noxious weeds. This data was entered into the GIS. Individual dots within the GIS represent individual plants, whereas larger patches of plants are depicted by polygons (Figure 2). Selecting the feature and viewing the data for each record can determine the identity of each dot or polygon (Figure 3). Information such as common and scientific name are included for each record. Other information might include evidence of digging, relative health of the plant, or, in the case of large patches of plants, number of individuals within the population and the area of the patch.
Prairie hyacinth (*Camassia angusta*), a plant ranked as rare and uncommon in Missouri, was discovered within the study corridor. A total of 222 of these plants were identified and mapped during 2002. In addition to the native species mapped, 143 individual plants of multiflora rose (*Rosa multiflora*) and 19 individual plants of musk thistle (*Carduus nutans*) were identified and mapped throughout the corridor during 2002. Both of these species are non-native noxious weeds.

Species that were not mapped but instead recorded as "dominant blooming species" for a section due to their relative abundance tended to be common throughout much of the Hwy 36 project corridor. Examples include compass plant (*Silphium laciniatum*) and partridge pea (*Chamaecrista fasciculata*). The species that were mapped and that are shown in Table 1, tended to be found in isolated pockets either throughout the corridor [as in the case of rosin weed (*Silphium integrifolium*) and black-eyed Susan (*Rudbeckia hirta*)], or they were only found as isolated pockets in one or two sections of remnant prairie throughout the entire corridor. Examples include New Jersey tea (*Ceanothus americanus*), prairie alumroot (*Heuchera richardsonii*), and prairie hyacinth.

Tables 2 and 3 illustrate species that were selected for re-mapping in 2003 and 2004, respectively, in order to see changes in blooming population size from year to year. The primary investigator selected species based on bloom time as well as interest to district roadside management staff. Wild quinine (*Parthenium integrifolium*), a species that was mapped in 2003, was not mapped in the initial mapping phase of 2002. Because of this, and in order to focus on mapping in other corridors during 2004, this species was not mapped again in 2004. The populations of selected species within the corridor changed over time (Table 4). During 2003, the populations of all species examined, with the exception of butterfly milkweed (*Asclepias tuberosa*), increased over the 2002 numbers. This was especially dramatic for prairie hyacinth and pale purple coneflower (*Echinacea pallida*). Populations of most species dropped again in 2004. The exceptions were butterfly milkweed and cream wild indigo (*Baptisia bracteata*). Both of these species increased. These differences may be due to fluctuations in the blooming population of plants since, for the most part, only blooming individuals were recorded. These fluctuations could be due to differences in weather patterns from year to year (annual rainfall, temperature, etc.) or they may simply be due to individual plants skipping bloom during a season in order to store up energy for the following year. The decline seen with musk thistle may be due to heavy predation in the previous years by the musk thistle flower head weevil (*Rhinocyllus conicus*).

This species eats the immature seed from within blossoms thus reducing viable seed production. More data is needed to test these hypotheses.

Land use adjacent to MoDOT right-of-way throughout the corridor appears to affect the presence/absence of prairie remnant. Based on the maps generated in the GIS, there appears to be a correlation between prairie remnant and railroad tracks adjacent to right-of-way. Additionally, prairie remnants within the corridor are within pre-settlement prairie. (Figure 4). This suggests that adjacent railroad rights-of-way provide prairie species with some level of protection and therefore they are able to persist. Most areas of prairie remnant throughout the corridor were south of Route 36 and adjacent to the railroad tracks. On the north side of Route 36, primary land use is agricultural fields and very few prairie remnants were located on this side of the roadway.

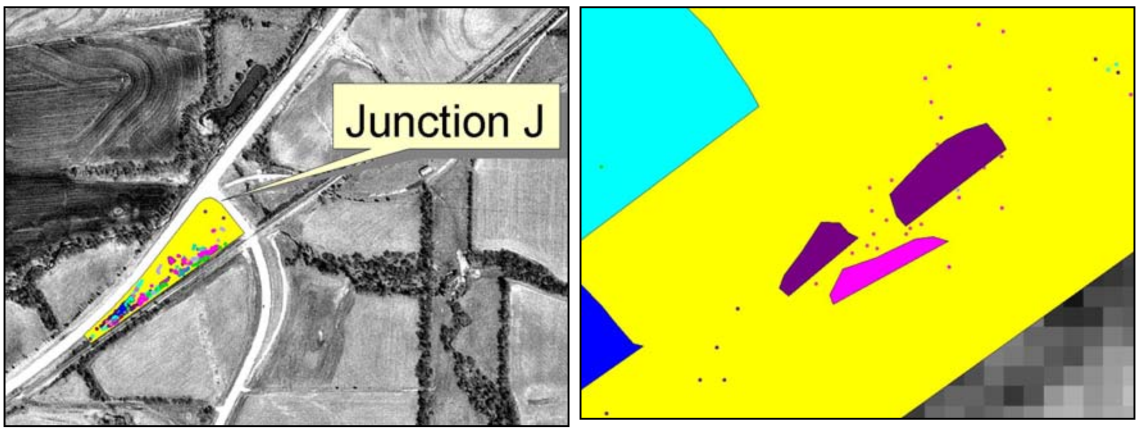

Figure 2: Example of a section of prairie remnant (yellow), as displayed in the GIS, with its species composition illustrated by polygons and dots of various colors that represent different species. On right is a close-up of a portion of the area.

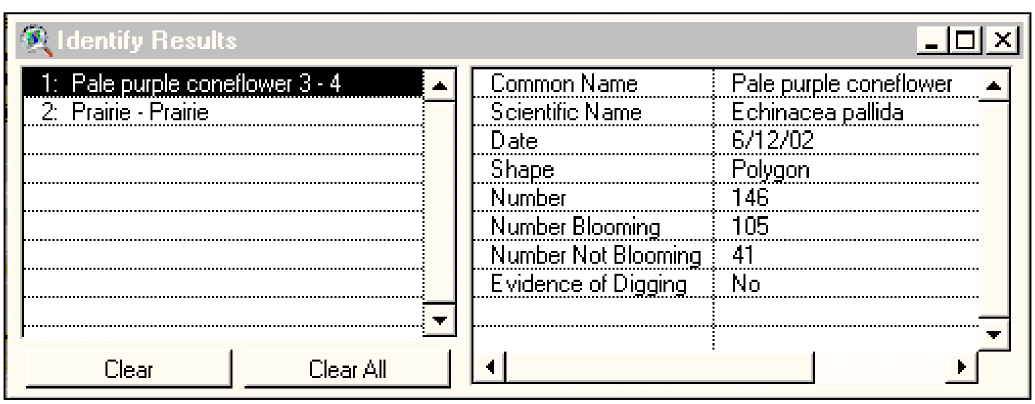

Figure 3: Identification window from ArcView. An example of the data associated with a feature. When a feature is selected (in this case, pale purple coneflower), the accompanying database is displayed.

Table 1: Species Mapped During Summer 2002

Date	Species	Scientific Name	# of Plants
5/23 & 28	Cream wild indigo	*Baptisia bracteata*	21
5/29	Indigo bush	*Amorpha fruticosa*	209
6/3	New Jersey tea	*Ceanothus americanus*	77
6/5-6	Foxglove beard tongue	*Penstemon digitalis*	605
6/6	Moth mullein	*Verbascum blattaria*	57
6/10-12	Pale purple coneflower	*Echinacea pallida*	3293
6/10, 18-20	White wild indigo	*Baptisia alba*	48
6/13	Prairie alum root	*Heuchera richardsonii*	245
6/18-20	Prairie hyacinth	*Camassia angusta*	222
6/20	Sneezeweed	*Helenium amarum*	-----
6/20	Purple meadow rue	*Thalictrum dasycarpum*	800
7/1	Butterfly milkweed	*Asclepias tuberose*	218
7/2	Black-eyed Susan	*Rudbeckia hirta*	473
7/8-10	Gray-headed coneflower	*Ratibida pinnata*	2352
7/11-16	White prairie clover	*Dalea candida*	1305
7/11-16	Purple prairie clover	*Dalea purpurea*	485
7/15-23	Rattlesnake master	*Eryngium yuccifolium*	3880
7/15-23	Culver's root	*Veronicastrum virginicum*	3403
7/15-24	Rosinweed	*Silphium integrifolium*	9003
7/24	Swamp milkweed	*Asclepias incarnata*	200
7/25-31	Prairie blazing star	*Liatris pycnostahya*	1930
7/31-8/8	Blue vervain	*Verbena hastata*	2805
7/31-8/7	False sunflower	*Heliopsis helianthoides*	449
7/31-8/7	Wild bergamot	*Monarda fistulosa*	105
8/6-8	Showy tick trefoil	*Desmodium canadense*	761
8/6	Winged loosestrife	*Lythrum alatum*	13
6/3-5	Multiflora rose (I)	*Rosa multiflora*	143
6/12	Musk thistle (I)	*Carduus nutans*	19

Total Plants Mapped —33,121 (I)- Non-Native Noxious Weed

Table 2: Species Mapped During 2003

Date	Species	Scientific Name	# of Plants
5/22	Cream wild indigo	*Baptisia bracteata*	47
5/28-29	Multiflora Rose (I)	*Rosa multiflora*	185
5/29-6/4	Wild Quinine	*Parthenium integrifolium*	1,054
6/9-16	Pale Purple Coneflower	*Echinacea pallida*	18,580
6/4-17	Prairie Hyacinth	*Camassia angusta*	4,559
6/24	Butterfly Milkweed	*Asclepias tuberosa*	92
8/4	Prairie Blazing Star	*Liatris pycnostachya*	2,482

Total Plants Mapped – 26,999 (I)– Non-Native Noxious Weed

Table 3: Species Mapped During Summer 2004

Date	Species	Scientific Name	# of Plants
5/24	Cream wild indigo	*Baptisia bracteata*	53
5/27	Multiflora Rose (I)	*Rosa multiflora*	135
6/07	Prairie Hyacinth	*Camassia angusta*	1,566
6/16	Pale Purple Coneflower	*Echinacea pallida*	5,201
6/18	Butterfly Milkweed	*Asclepias tuberosa*	179
7/27	Prairie Blazing Star	*Liatris pycnostachya*	1,471

Total Plants Mapped – 8,605 (I)- Non-Native Noxious Weed

Table 4: Comparison of Selected Species Mapped on Highway 36 Corridor 2002 – 2004

Species	Summer 2002	Summer 2003	Summer 2004
Prairie Hyacinth	222	4,559	1,566
Pale Purple Coneflower	3,293	18,580	5,201
Butterfly Milkweed	218	92	179
Cream Wild Indigo	21	47	53
Prairie Blazing Star	1,930	2,482	1,471
Multiflora Rose (I)	143	185	135
Phragmites (I)	1160 sq. meters	1160 sq. meters	936 sq. meters
Musk Thistle (I)	19 plants	1,658 sq. meters	533 sq. meters

(I)- Non-Native Noxious or Invasive Weed

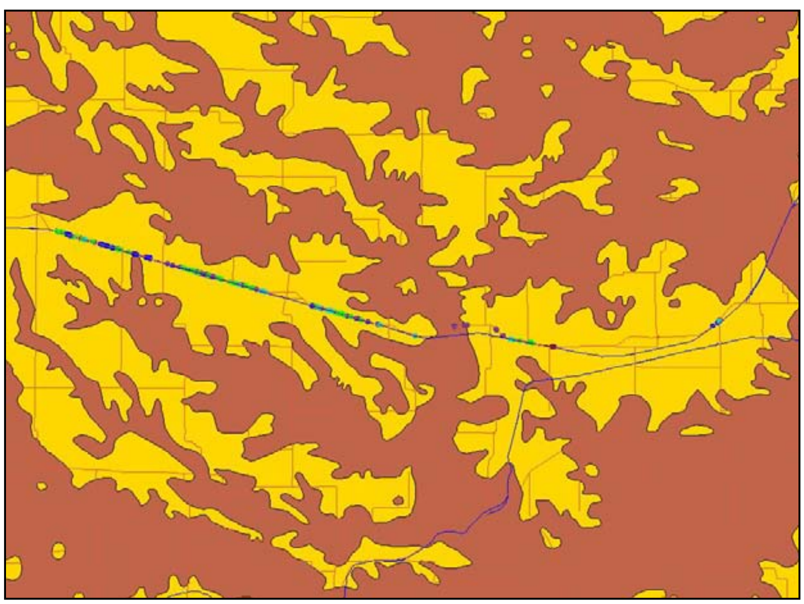

Figure 4: Section of a display in the GIS illustrating highways (red lines), railroad tracks (blue lines), pre-settlement prairie data (yellow), and various colored dots representing native prairie species that we mapped along the Route 36 Corridor. Note that prairie species mapped along the roadside correlate well with adjacent railroad tracks and that all of the mapped species are located within pre-settlement prairie remnant. Pre-settlement prairie data was obtained from the Missouri CARES website: www.cares.missouri.edu.

In order to view comparisons of predominant blooming species from year to year and from month to month within a year, we randomly selected five remnant sections from the approximately 325 for which we have predominant blooming species data, and compared the data for each section. The results are depicted in Tables 5 – 7. In general, it appears that blooming populations of "weedy" species such as parsnip (*Pastinaca sativa*), poison hemlock (*Conium maculatum*), Queen Anne's lace (*Daucus carota*), and dogbane (*Apocynum cannabinum*) are relatively stable within a remnant section from year to year. More desirable species like prairie rose (*Rosa setigera*), blue vervain (*Verbena hastata*), wild bergamot (*Monarda fistulosa*), and foxglove beardtongue (*Penstemon digitalis*) show up as predominant blooming species in a section during one or possibly two years but not consistently over the three-year period. Compass plant (*Silphium laciniatum*) is a desirable native species that appears relatively consistent as a predominant blooming species in some sections from year to year, and in other sections may only show up during one or two years. We've noticed that compass plant seems be a stronger bloomer on our roadsides in northeast Missouri some years as opposed to others. We've also noticed that in certain years, populations of this plant appear to be infected with a disease that prohibits normal growth and blooming. Besides the possibility of disease, reasons for annual fluctuation of blooming in this and the other species may be the same as those mentioned previously (temperature, rainfall, etc).

The tables also illustrate the cycle of blooming species as the season progresses. Compass plant is not blooming in June, but appears common in July and is still present as a predominant blooming species in August. Blue vervain shows up in July and is not present in June or August. Ironweed (*Vernonia fasciculata*) shows up as a predominant blooming species in one section of remnant in August but is not present earlier, and it was only recorded in one section during one year.

Table 5: Mid-June Predominant Blooming Species for Selected Remnant Sections

Section #	2002	2003	2004
1	Spiderwort, yellow sweet clover, low bindweed	Common milkweed, parsnip	Common milkweed, parsnip, spiderwort
91	Prairie rose, yellow sweet clover, common St. Johnswort	Dogbane, spiderwort, bindweed, poison hemlock, parsnip, foxglove beardtongue	Spiderwort, poison hemlock, parsnip
175	Prairie rose, spiderwort, common milkweed	Parsnip, spiderwort, yarrow	Yellow sweet clover, Queen Anne's lace, parsnip
290	Dogbane, common milkweed, spiderwort	Common milkweed, spiderwort, dogbane, elderberry	Elderberry, dogbane, poison hemlock
307	Dogbane, parsnip, poison hemlock, common milkweed, spiderwort, daisy fleabane	Dogbane, parsnip, elderberry, poison hemlock	Poison hemlock, Queen Anne's lace, parsnip, common milkweed

Table 6: Mid-July Predominant Blooming Species for Selected Remnant Sections

Section #	2002	2003	2004
1	Compass plant, chicory, Queen Anne's lace, common milkweed	Compass plant, Queen Anne's lace, common mullein, common milkweed	Compass plant, chicory, Queen Anne's lace, wild bergamot
91	Compass plant, white sweet clover, flowering spurge	Compass plant, common mullein, gray-headed coneflower, rosinweed, spiderwort	Blue vervain
175	Compass plant, wild quinine, hairy wild petunia, yellow sweet clover, partridge pea, Queen Anne's lace	Queen Anne's lace, flowering spurge, gray-headed coneflower	Gray-headed coneflower, Queen Anne's lace
290	Blue vervain, common milkweed, poison hemlock, dogbane, wild bergamot	Scurfy pea, poison hemlock, dogbane, common mullein, common milkweed	Poison hemlock, dogbane
307	Blue vervain	Common milkweed, Queen Anne's lace, bindweed, rosinweed	Bindweed, Queen Anne's lace, rosinweed

Table 7: Mid-August Predominant Blooming Species for Selected Remnant Sections

Section #	2002	2003
1	Compass plant, Queen Anne's lace, ironweed, chicory, flowering spurge	Chicory, wild bergamot, compass plant, Queen Anne's lace
91	Compass plant, ironweed, flowering spurge	Bindweed, compass plant, rattlesnake master
175	Chicory, partridge pea, compass plant, flowering spurge, Queen Anne's lace	Queen Anne's lace, compass plant, gray-headed coneflower, flowering spurge
290	Dogbane, ironweed	Wild bergamot, dogbane
307	Early goldenrod, ironweed, flowering spurge	Wild bergamot, gray-headed coneflower

The results of this portion of the study indicate that GPS/GIS technology will aid vegetation managers in identifying the locations of prairie remnant, their species compositions, tracking population trends over time in response to management practices, and identifying relationships with other variables. Repeated mapping and the addition of data to the GIS will result in better management of this valuable natural resource.

Route 61 Corridor

The mapping of the selected non-native noxious weeds on right-of-way in Pike County along Route 61 resulted in baseline population data for musk thistle, common teasel, and cut-leaf teasel. The data, which are summarized in Table 8, indicate that the population of common teasel was slightly lower in 2004 than in 2003. Cut-leaf teasel increased slightly. Musk thistle was not mapped during 2004 because a visual assessment of the areas where it had been located within the corridor in 2003 revealed that individual plants were scattered and the population was down. This may have been due to heavy weevil infestations in previous years. Random sampling of musk thistle populations by the principal investigator throughout northeast Missouri in 2002 and 2003 indicated that the weevil populations were high and seed production would therefore be expected to be low during those years. Since musk thistle is a biennial, it would not be surprising to see population numbers decline in years following heavy seed predation by the weevil. Future mapping of musk thistle patches should also include an assessment of weevil presence and this data should be added as an attribute to the GIS database.

In addition to mapping the perimeter of patches of both common and cut-leaf teasel, in 2004 we added a descriptive term indicating relative abundance of individuals within a patch. In the field, we recorded relative patch density as either scattered, medium, or heavy. This was added to the attributes table in the GIS and it will provide a tool for assessing future changes in density within individual patches.

The data collected for these species will be valuable when comparing future mapping data collected in the same areas after various control strategies are utilized. This will aid vegetation managers and maintenance forces to effectively analyze the relative success or failure of various methods and products. The results show that GPS/GIS technology can be successfully used to identify noxious weed locations and track their spread.

Table 8: Comparison of Noxious Weed Mapping

Species	Acreage Summer 2003	Acreage Summer 2004
Common Teasel	4.1	3.7
Cut-leaf Teasel	4.6	4.8
Musk Thistle	2.14	-----

Route 54 Corridor and Route Z Lincoln County Area

The results and discussion of these locations are included together because the objectives for mapping each of these areas were similar. Pale purple coneflower is present at both locations and we mapped individual plants and patches at both locations to establish baseline population data for each site. Future mapping at each location will reveal annual fluctuations such as those observed at the Route 36 corridor. This additional data will also be useful for comparisons between these two sites and with other locations where pale purple coneflower has been recorded (such as the Route 36 Corridor). This will allow us to see if annual fluctuations follow similar patterns across various populations in northeast Missouri, or if these fluctuations are localized within the corridors themselves.

Eastern gama grass (*Tripsacum dactyloides*) is a native tallgrass prairie species which was previously common on northeast Missouri roadsides. However, with the spread of johnsongrass (*Sorghum halepense*), a non-native noxious weed species with a similar appearance, eastern gama grass was mistakenly sprayed with herbicides and the populations declined. In recent years, this species appears to be making a comeback, perhaps due in part to MoDOT utilizing a different herbicide to control johnsongrass. This new herbicide does not kill eastern gama grass so even if the plant is mistakenly sprayed, it will survive. The Route 54 Corridor contains many individual gama grass plants, as well as small patches. It was an ideal location to map this species in order to establish a baseline population for future mapping. The location also contains pale purple coneflower, as mentioned above, and there are many other native prairie species that may be mapped in the future.

The mapping of pale purple coneflower resulted in 888 individual plants and their locations recorded in the GIS for the Route 54 Corridor. At the Route Z Area, 1,104 individual plants and their locations were recorded. We also looked for evidence of digging at each area since this species is sometimes collected illegally from our roadsides for ornamental and medicinal purposes. Although we have seen evidence of digging at each of these locations in the past, no evidence was noted during the 2004 mapping session. It is possible that cultivation of this species for both ornamental and medicinal purposes in recent years has alleviated some of the pressure on wild populations by collectors.

The mapping of eastern gama grass at the Route 54 Corridor resulted in 23 individual plants and approximately 73 square meters of patches in the area. Future mapping will reveal population fluctuations and these can be compared to johnsongrass control measures in the area to see if these measures are having a positive or negative effect on the gama grass.

The results of this portion of the study, like the results for the Route 36 portion, indicate that this technology is a valuable to identify the locations of species of interest and to document other pertinent information about them. Tracking the effects of such actions such as digging or herbicide use will provide data that can be used to identify solutions to these problems.

Native Conversion Projects

Early in the 2004 mapping session, Roadside Operations staff at the Central Office asked if we could assist them with the GPS mapping of potential native wildflower and grass conversion sites. The conversion projects are a joint partnership between MoDOT and the Missouri Department of Conservation (MDC) utilizing federal transportation enhancement funds to perform the work on MoDOT right-of-way. The goal was to take rights-of-way that contained large patches of non-native or invasive weeds, eliminate the existing vegetation, and re-seed the areas with native vegetation. Since the projects were to be contracted, Roadside Operations Central Office personnel were exploring ways to illustrate the boundaries of the conversion sites in bid packets for contractors wishing to perform the work. We agreed to use our GPS/GIS equipment to test its abilities in this area. Four sites were selected throughout Missouri and in June 2004, we traveled to the sites with MoDOT Central Office Roadside Staff to walk the perimeters of the sites with GPS receivers so that the mapped boundary data could be entered into a GIS. The proposed sites were large and instead of walking the entire perimeter of each, we decided in the field to record landmarks at the edges of the proposed sites in a notebook and simply map a small (10’ x 10’) area within

the proposed conversion area. In the office, we displayed the small mapped areas in the GIS, overlaid the data on DOQQ basemaps, and used our field notes to determine where the actual boundaries were on the DOQQ's. We then expanded the boundaries of our small field-mapped areas to match the desired boundaries of the proposed conversion sites. We displayed the proposed conversion areas in yellow in the GIS, used the GIS to calculate the acreage of each proposed conversion site, produced the desired bid packet maps, and provided all of these products to both MoDOT Roadside Operations Central Office staff, and MDC staff. An example of one of these maps is shown in Figure 5 below. Table 9 illustrates the acreage of each proposed conversion site.

This portion of the study allowed us to explore manipulation of field-collected data within the GIS. This illustrates the power and flexibility of the GIS as a data manipulation tool and not just a means for displaying and organizing spatially oriented data. Data collection using GPS technology is just the first step in the GIS process. The majority of the data analysis and manipulation occurs in front of the GIS. This saves time in the field and that, in turn, frees up personnel and equipment for other uses. If the GIS had not allowed us to alter the boundaries of our mapped areas, we would have spent many more hours in the field. This may have meant multiple trips to the same sites and possibly overnight trips to the more remote locations. Not only was time saved, but taxpayer dollars were also saved due to the power of good GIS software.

Table 9: Proposed Native Conversion Sites Mapped June 2004

Location	Acreage
Independence	61.64
Kingdom City	46.27
Lamar	32.38
Bethany	45.34

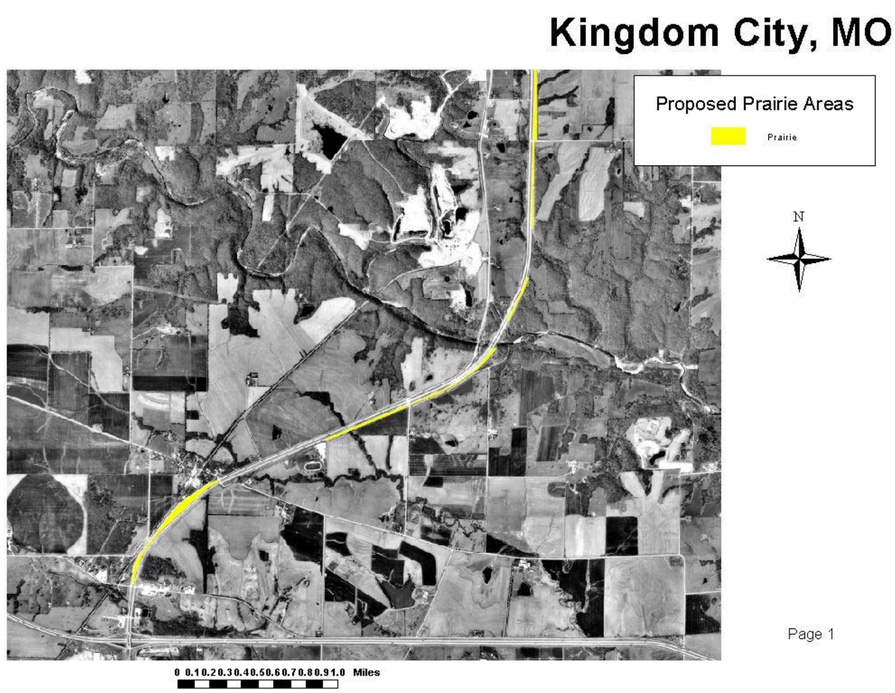

Figure 5: Example of one of the maps provided to MDC and MoDOT staff illustrating the proposed conversion sites overlaid on DOQQ imagery.

Roadway Features Inventory

The mapping of roadway features along the 10-mile section of Highway 36 from west of Monroe City to Route J, Ralls County, resulted in the following data:

132 signs – location and type
130 underground utility markers – location and type of utility
33 driveways – location along with size and type of drainage structure
25 concrete box culverts – location and size
2 lettered state route intersections – location along with size and type of drainage structure
5 county road intersections – location along with size and type of drainage structure
2 shoulder changes – location and type of change
1 pavement change – location and type of change
30 no passing zones – location and direction of zone

These data were collected in the field by driving or walking to features and standing adjacent to them as their locations were mapped and their attributes recorded. This is the same procedure that was used for mapping vegetation for the environmental roadside inventory. Figure 6 illustrates a section of the roadway features inventory in the GIS. Selecting a feature on the map using the identification capabilities of the GIS allows the user to determine the name of the feature and its associated attributes.

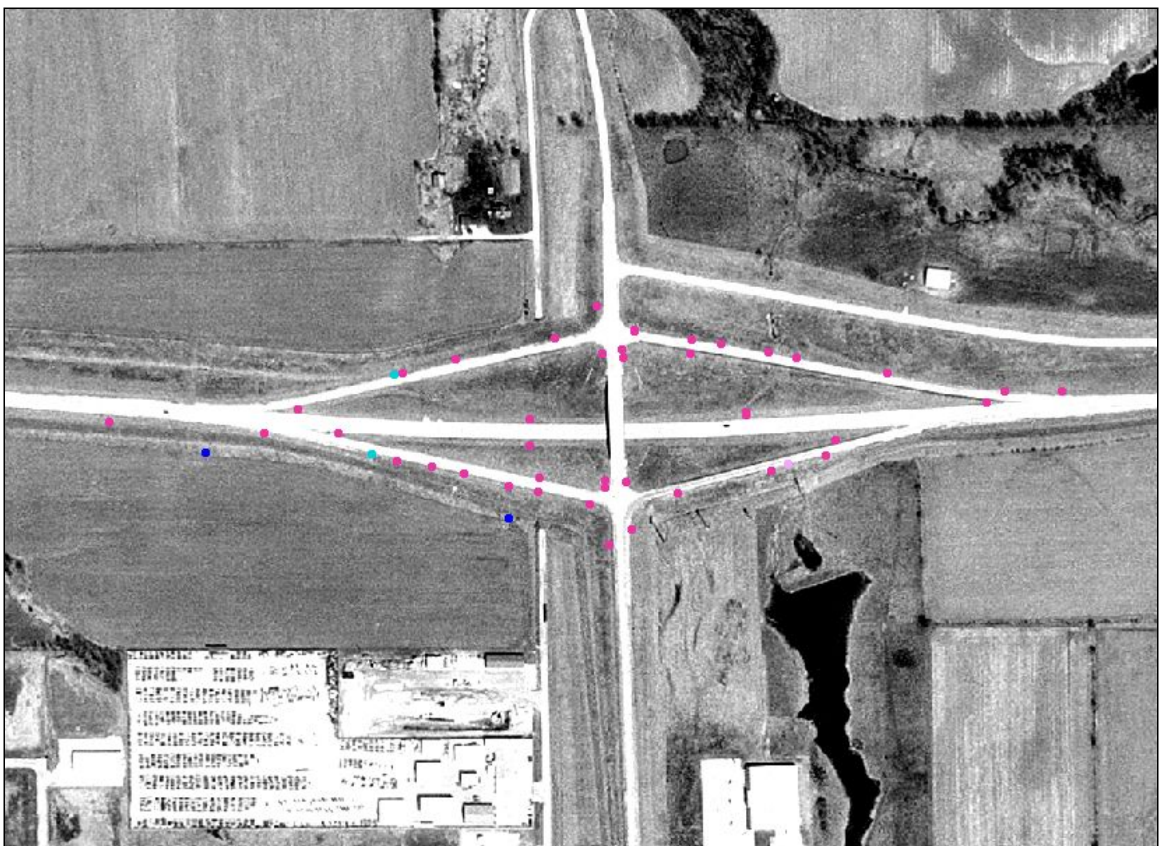

Figure 6: A selection from the Roadway Features GIS that illustrates signs (dark pink), underground utilities (dark blue), drainage pipes (light blue), and a concrete box culvert (light pink). Selecting any of these features using the "identify" tool in ArcView will open a window with the attributes of the selected feature.

There are many potential benefits of knowing where roadway features assets are located and being able to access important information about each of these features from one location. The GIS performs this task and displays all of this information in a spatial context on a map thus allowing viewers to see where attention is needed. However, the methods we used for data collection in the field were time consuming. Data collection for the 10-mile test corridor lasted approximately 30 hours. Based on these numbers, it would take nearly 280 weeks to complete an inventory of every state-maintained roadway in the Northeast District. This estimate does not take into account weather delays, travel time to distant parts of the district, or differences in the density of roadway features on different roads. Finding the time and personnel to perform this duty would be a challenge. However, initial data collection would require more time than subsequent field checks to update information in the GIS. If data could be collected in the field in a more efficient manner, or if data regarding the location and attributes of various features currently exists elsewhere, then this data may be able to be incorporated in the GIS with much less time spent in the field. One possible collection technique for a roadway features inventory is already being used by Central Office GIS Coordinator Arnold Williams. This technique involves driving roadways with a GPS beacon placed on top of the vehicle and attached to a voice activated computer system. The system can be programmed to map desired features by simply saying various commands while driving. A laser range finder can be used collect distance measurements from the GPS and this information can be used to correct the location of the feature in the GIS. This technique can save time collecting data in the field.

The data collected were not integrated with MoDOT's TMS system as we had planned prior to beginning this portion of the study. Due to the time consuming method of data collection, and because Central Office staff were already looking at ways to more efficiently collect roadway features data, we felt that there was no need to pursue data integration of this type any further.

Conclusions and Recommendations

The results of the study indicate that spatially oriented databases can be an effective tool to catalog information concerning the location and status of prairie remnants, the species that are contained in them, noxious weeds, and roadway features. The results also indicate that GPS/GIS technology can be a powerful tool for planning purposes as illustrated in the native conversion portion of the project. The data collected thus far provide baseline information to track how MoDOT's vegetation management policies affect native species within the prairie remnants. The information gathered about noxious weed populations will allow for more accurate location and assessment of control measures for these species. Additionally, the data allow MoDOT to pinpoint areas to focus on for seed collection to proliferate native ecotype seed on state rights-of-way throughout Northeast Missouri. We recommend that data collection continue throughout the coming years in order to add new species to the GIS. Continuation of re-mapping and counting the species already sampled will also facilitate tracking the relative density and health of these plant populations.

During the course of the project, we have attempted to transfer information from this database into the on-board computer system of a GPS equipped herbicide sprayer to test compatibility and functionality of the data in herbicide applications. We have had some limited success in this area. The goal is for the computer system in the herbicide sprayer to alert the operator when sensitive prairie remnants or species are present so that the applicator can avoid these areas. Conversely, the computer system should alert the operator when populations of target species such as noxious weeds are present. Software and coordinate system incompatibilities have hampered our efforts to integrate field-collected data with the systems in the sprayers. We have had some success integrating data from the sprayer systems with the GIS due to advances in our GIS software (MoDOT switching from ArcView 3.X to Arc9). We will continue to work on these incompatibility issues but we recommend that MoDOT investigate replacement of the GPS/GIS systems in the herbicide sprayers (currently the Roadside Maintenance System – RMS) with software and hardware that meet MoDOT's compatibility requirements. Until such issues are addressed, it will be difficult to advance this technology in MoDOT's roadside vegetation management program. The cost of upgrading the systems on MoDOT's five GPS-equipped sprayers is unknown. The newest upgrade by the manufacturer (Midwest Technologies) to the RMS system does not meet MoDOT's specifications for a system that is able to

record and display data in Universal Transverse Mercator (UTM) coordinates. Therefore, it is likely that a non-RMS based system will have to be installed in these units. This will have to be performed on contract since MoDOT does not have the expertise to perform such an operation.

Additional spatial data such as locations of wetlands, streams, ponds, lakes, and other bodies of water, threatened and endangered species, and other natural features can be added to the database to create a more comprehensive environmental roadside inventory. Some environmental data already exists in TMS, however new data collected in the field will result in a more complete GIS. Such an inventory will be beneficial for assessing the impacts of non-vegetation management maintenance operations such as drainage improvements and trenching on highway rights-of-way, and also impacts relating to new construction of roadways and other features. Future transportation improvements, such as additional lanes of highway, require National Environmental Policy Act (NEPA) compliance. A comprehensive roadside environmental inventory could provide baseline data needed to complete certain aspects of the required environmental work and eliminate assumptions of ecosystem value and avoid or minimize mitigation requirements made by other resource agencies.

Data collection for an environmental roadside inventory, like that of roadway features, is a time consuming task. In fact, it is much more time consuming than collecting roadway features data because there are many more features (individual plants or patches) that can be inventoried. However, unlike a roadway features inventory, it would be very difficult to try to perform detailed mapping functions for an environmental roadside inventory, like those in this study, from a moving vehicle or from a vehicle parked on the shoulder of the roadway. Roadside vegetation managers wishing to pursue a roadside environmental inventory program will have to prioritize and focus their efforts on species or problems that are of the most importance to them and their district's needs. They will also have to allocate resources and personnel to their programs. We recommend the use of college interns to perform data collection and entry functions. Use of such personnel is beneficial to MoDOT economically. The intern also receives many benefits. Students in the fields of biology, botany, geology, and other related areas, can benefit from the hands-on field experience that they receive while earning a wage from MoDOT in this capacity. They will sharpen their plant identification skills, they will become familiar with the equipment and software, and they will see MoDOT as an environmental steward. Not only do they receive valuable on the job experience that will be helpful to them as they pursue their degrees and subsequently enter the workforce, but they also relay to others in their field MoDOT's commitment to environmental responsibility.

In summary, the use of spatially oriented databases to manage MoDOT's natural and man-made resources is in its infancy. However, based on the results of this study, GPS/GIS technology will be a valuable tool for MoDOT managers across the state as they try to find ways to increase efficiency in their jobs.

Implementation Plan

The results of this project illustrate the benefits of GPS and GIS technology for resource inventory and management. We recommend implementing the use of this technology on a statewide basis for all aspects of roadside and roadway features. However in this section, we will only discuss implementation as it relates to an environmental roadside inventory for vegetation management purposes. As previously discussed, the methods used to create the roadway features inventory are too time consuming to recommend for broad application, especially in light of the ongoing GIS-based asset management efforts by Central Office planning and GIS staff.

The environmental roadside inventory that has been developed in this project will continue to expanded and consulted for various vegetation management practices. It will also be used to assess the dynamics of populations of selected native species as well as noxious and invasive species. With successful integration with the GPS-equipped herbicide sprayers, the inventory can be used to accurately target undesirable species and record applications to control these species. The benefits of using this technology are many. Therefore, we recommend that other districts apply the findings of this study to their own vegetation

management programs. Programs similar to the one developed through this study can be created and implemented in other districts and tailored to meet their vegetation management needs.

The results of this study will be presented to other MoDOT roadside personnel at the next statewide annual meeting (unscheduled at the time of this writing). At that time, personnel interested in serving on an implementation team will be identified. Rand Swanigan, Roadside Management Specialist from the Central Office has agreed to serve as Principal Investigator for the statewide implementation portion of this project. Chris Shulse, Principal Investigator for the current project, will also serve on the team and will share the knowledge and experience gained from this project in planning statewide implementation. The objective of statewide implementation will be to improve the efficiency and accuracy of our vegetation management practices by mapping the locations of vegetation species of interest, incorporating this data in GIS's, and using these as tools to target and track the effects of our management techniques.

Divisions Affected by Implementation

Implementation of a statewide roadside environmental inventory will affect several divisions in MoDOT. The following divisions and their respective contacts are listed below:

System Management – Don Hillis
- Stacy Armstrong, Roadside Management Supervisor, and Rand Swanigan, will be the primary contact.

Organizational Results – Mara Campbell
- Patricia Lemongelli, Research, Development, and Technology Director, will be the primary contact.

Transportation Planning – Machelle Watkins
- Arnold Williams, GIS Coordinator, will be primary contact.

Information Systems – Mike Miller
- Primary contact unknown at this time.

Environmental Studies – Kathy Harvey
- Gayle Unruh, Wetland Coordinator, and Bill Graham, Environmental Compliance Coordinator, will be the primary contacts.

Implementation Period

It is expected that implementation could begin in FY '07, depending on budgetary constraints. An implementation team will be formed during the fall of 2005 and winter of 2006. The team would be responsible for finalizing a plan for implementation and determining how best to focus the use of this technology at the statewide level. This would also involve developing the infrastructure for reporting results and communicating information contained in each district's roadside environmental inventory GIS. Training of staff to use the GIS software Arc9 would take place during spring and early summer 2006. If budgets allow, equipment could be purchased in July of 2006 and staff would be trained to use the equipment in late summer of 2006. Mapping of species and implementation of techniques would be fully operational by summer of 2007.

Funding for equipment and personnel would come from within each district's budget. It is estimated that equipment purchases for each district would range from $5,000 to $10,000 and would be charged to Activity R41A – Support, Improve Roadside Appearance. Equipment purchased would include a quality, hand-held GPS unit for data collection in the field, as well as a quality digital camera with 3 – 4 megapixel resolution capabilities. Most computers currently owned by MoDOT should be capable of running the GIS

software Arc9, as well as software such as Pathfinder Office or Terra Sync Software that enables the GPS unit to download data into the GIS. This software is included with the purchase of the GPS unit at no additional charge. Some districts may have to upgrade their computer systems and therefore, a higher cost of equipment purchases of up to $10,000 may be possible in these cases.

Personnel cost would be very low for summer interns. It is estimated that an intern on staff for three months during a single summer would cost approximately $4,500 (450 hours x approx. $10/hr). Full-time staff would spend time developing and implementing the program. Costs associated with full-time staff participation are unknown at this time. The implementation team will be responsible for determining the level and cost of staff involved with use of this technology, the creation of a detailed budget, and a detailed procedure for implementation.

Bibliography

Brandley, Jim. 2001. Public works department merges data into a central management system. Kirchner, J.R. (ed.) Public Works Magazine. 132(3):22-24.

Carr, M. H., P. D. Awick, T. Hoctor, W. Harrell, A Goethals, and M. Benedict. 1998. Using GIS for identifying the interface between ecological greenways and roadway systems at the state and sub-state scales. Pages 68-69 *In* G. L. Evink, P. A. Garrett, D. Zeigler, and J. Berry, eds., Proceedings of the International Conference on Wildlife Ecology and Transportation. Fort Myers, Florida, February 10-12, 1998. 263pp.

Lang, Laura. 2000. Managing Natural Resources with GIS. ESRI Press.

Marum, Elizabeth. 2000. GPS helps manage roadside vegetation. Roads and Bridges Magazine. May: 36-38.

Noe, Curt. 2000. GIS-based life cycle management of highway assets. Kirchner, J.R. (ed.) Public Works Magazine. 131(9):30-34.

Shulse, C., A.Houchins, T. Wren, and S. Armstrong. 2003. Using spatially oriented databases as a tool to manage roadside prairie remnants. Pages 111 – 115 *In* S. Fore (ed.) Proceedings of the 18th North American Prairie Conference: Promoting Prairie. Kirksville, Missouri, June 23 – 27, 2002. 249 pp.

Shulse, Chris. 2004. Development and implementation of a roadside environmental inventory – RI01-007 – Status Report. Missouri Department of Transportation Research, Development, and Technology publication.

Steele, Sharon. 2000. GIS and public works: toward smarter government. Kirchner, J.R. (ed.) Public Works Magazine. 131(6):16-18.

Appendix A: Research Work Plans

Following are the two research work plans that were submitted to MoDOT's Research, Development, and Technology Division in order to obtain funding for this project. The initial work plan, submitted March 27th, 2001 requests funding for the initial environmental roadside inventory portion of the project. The second work plan, submitted December 12th, 2002, requests additional funding to expand the project to include mapping and development of the roadway features inventory.

Research Work Plan

Date: **March 27, 2001**

Project Number: **RI01-007**

Title: Development and Implementation of Environmental Roadside Inventory

Research Agency: MoDOT -- Maintenance Division personnel in both District 3 and General Headquarters, as well as Design/Environmental Studies personnel at General Headquarters.

Principal Investigators: Chris Shulse, Roadside Manager – principal investigator
Gene Gardner, Senior Environmental Specialist – resource
Terri Wren, Senior Cartographer – resource
Stacy Armstrong, Roadside Management Supervisor – resource

Objective: Develop an environmental roadside inventory (using GPS and GIS technologies) that will be incorporated into the district roadside management plan. A spatially accurate roadside vegetation inventory will be created through GPS data recording along a 36-mile section of Route 36. Special emphasis will be placed on environmentally sensitive areas within MoDOT rights-of-way in order to develop a more comprehensive and responsible roadside vegetation management plan for District 3. This information will be incorporated into a GIS system and will then be used to develop mowing, herbicide and vegetation management strategies for the corridor. The resulting database will also prove valuable for identifying and managing possible environmental impacts associated with route improvements in the future.

The techniques, data, and implementation experiences resulting from this project will be shared with roadside managers across the state. Other districts can then benefit from the experiences in District 3 in establishing their GIS-based roadside vegetative management strategies.

Background and Significance of Work: GPS and GIS are now successfully used in MoDOT environmental and roadside maintenance work. Environmental Studies personnel in Design at General Headquarters currently use GIS/GPS technology to map and integrate information about wetlands, endangered species, and cultural resources. The new injection herbicide spray units located in the districts also have GPS units on board which can be used to map areas of herbicide application and areas that are sensitive to these applications. However, the use of GIS/GPS technology to expand the inventory of roadside features is in its infancy at MoDOT.

Environmental and management concerns for roadside management include such issues as the use of herbicides, cost and frequency of mowing, hydrology, invasive plant species, and the restoration and preservation of native plants and animals. The use of GIS/GPS in roadside vegetation management can be a very powerful tool for gathering data about areas of concern such as noxious weed infestations, disease or pest outbreaks, and areas sensitive to mowing or herbicide applications. MoDOT's herbicide and mowing practices can be refined with an environmental roadside inventory. Identification of grass species and their locations allow more prudent herbicide applications, reduced mowing costs in areas of certain types of natural vegetation, and overall better management of the right of way.

The use of native vegetation on roadsides will continue to increase. Use of these species has been shown to reduce maintenance costs, please the public, and is recognized by resource agencies as an indicator that MoDOT is a good resource steward. Knowing what plant species we have and where we have them will yield valuable information. Seed sources from MoDOT right-of-way can be used to increase stands of native or critical vegetation. We currently have no efficient or accurate methods of keeping track of our roadside vegetation.

Future improvements within corridors will also require NEPA environmental clearance. A roadside environmental inventory will provide the baseline data needed to complete the required environmental work and eliminate assumptions on ecosystem value and mitigation measures made by other resource agencies.

Roadside vegetation information developed through GPS field coding and GIS application will allow roadside managers and other MoDOT decision makers to better manage roadside appearance while making informed decisions about mowing and herbicide use.

The environmental roadside inventory also aids in developing and maintaining the "Total Driving Experience" for the public. Our roads are often all that travelers see of Missouri, it behooves us to make this impression count.

The use of GIS/GPS technology in the field operations at MoDOT can be a very powerful and very effective tool for enhancing the overall effectiveness of our workforce. Use of this tool in field operations - such as Roadside Management - will allow for better roadside management decision-making. Establishing a roadside vegetation inventory also demonstrates to other agencies MoDOT's commitment to environmental stewardship.

Action Plan:
Step 1 – Form team of Principal Investigators and develop procedure (complete).
Step 2 – Obtain funding for project.
Step 3 – Obtain equipment (GPS unit, computer hardware, software and licensing).
Step 4 – Collect data.
Step 5 – Compile and analyze data.
Step 6 – Report results.
Step 7 – Provide model of adoption for other districts to create environmental roadside inventories.

Literature Search: In Florida, researchers at the University of Florida have been using GIS to identify landscape features that could be incorporated into an ecological greenways network (Carr et al. 1998). In coordination with the Florida DOT, Florida Game and Fresh Water Fish Commission, and

Florida Natural Areas Inventory, natural areas and wildlife sites were identified and a plan was developed for protection and linkage of significant natural landscapes, which included roadside management.

When considering the social and economic impacts to communities as a result of transportation facility development, the Federal Highway Administration has stated that the aesthetic qualities of streets and roads are often more important to the qualities of their surroundings than are the aesthetic qualities of the properties to which they provide access. There is a growing concern among professionals and citizens that in designing roads we have increasingly, and unnecessarily, neglected aesthetics and other community values (Passonneau 1996).

Highways have long been considered to have an adverse impact on wildlife, but until recently very little work has been completed to determine how to minimize these impacts. A major management objective for the Washington State Department of Transportation developed some partnering studies to identify significant wildlife travel corridors and maintain habitat connectivity through appropriate roadside vegetation management (Wagner et al. 1998). Identifying areas where native vegetation currently provides habitat and ensuring connectivity of these grassland habitats by managing Missouri roadsides could make a cost-effective contribution and facilitate the goals of a number of state and federal agencies in Missouri.

Various utility companies throughout the country are beginning to create spatially oriented databases with information about the vegetation within their corridors. The information gathered is integrated with local government, utility asset, and other environmental data including National Heritage and Endangered Species Program. The maps are used by utility company decision makers, including field personnel, when applying herbicides, removing unwanted vegetation, or other operations that can impact wildlife and the environment (ESRI Press Release 3/2000 www.esri.com).
Other agencies, both governmental and private, are using GIS applications to manage vegetation. The U.S. Forest Service is using spatially oriented vegetation maps of public lands to locate optimal habitat for threatened and endangered species. The World Resources Institute (WRI) uses GIS data and maps to study worldwide deforestation and to identify the threats to frontier forests (Lang, 2000). The concepts developed by WRI can be applied on a regional level when looking at stands of native vegetation on roadsides, and identifying threats to their survival.

Carr, M. H., P. D. Awick, T. Hoctor, W. Harrell, A Goethals, and M. Benedict. 1998. Using GIS for identifying the interface between ecological greenways and roadway systems at the state and sub-state scales. Pages 68-69 *In* G. L. Evink, P. A. Garrett, D. Zeigler, and J. Berry, eds., Proceedings of the International Conference on Wildlife Ecology and Transportation. Fort Myers, Florida, February 10-12, 1998. 263pp.

Lang, Laura. 2000. Managing Natural Resources with GIS. ESRI Press.

Passonneau, Joseph. 1996. In the design of roads: aesthetics and other community values. Transportation Research Coard 75th Annual Meeting, January 7-11, 1996. (abstract)

Wagner, P., M. Carey, and J. Lehmkukl. 1998. Assessing habitat connectivity through transportation corridors on a broad scale: an interagency approach. Pages 66-67 *In* G. L. Evink, P. A. Garrett, D. Zeigler, and J. Berry, eds., Proceedings of the International Conference on Wildlife Ecology and Transportation. Fort Myers, Florida, February 10-12, 1998. 263pp.

The following resources can be used for further information about the use of GIS and GPS in vegetation management:

Proceedings of the International Conference on Ecology and Transportation
National Roadside Vegetation Management Association Annual Convention Minutes
ESRI website (www.esri.com)

Method of Implementation: As the investigation proceeds, the developing GIS database will be consulted in developing management strategies for roadside sections. Once the investigation is complete, the investigators will present their experiences with equipment, data collection, and implementation examples Roadside Managers, Supervisors, and other appropriate maintenance personnel from other districts during a semi-annual meeting of roadside personnel. Assistance will be provided to other districts in establishing environmental roadside inventories.

Anticipated Benefits:

A) Provides data and direction for Roadside Management system

1) Accurate management of herbicide applications saving cost and labor.
2) Increased efficiency of mowing operations results in cost and labor savings.
3) Frees up labor normally spent on mowing and spraying for use on other tasks.
4) Identification of areas for collection of native grass and wildflower seed.
5) Identification of areas with erosion, noxious weed, or other maintenance problems.
6) Increased safety to the public and employees due to more efficient mowing and spraying operations that result in less exposure to chemicals and equipment.
7) Increase in public's perception of aesthetically pleasing, environmentally sound roadsides ("Total Driving Experience").

B) Establishes MoDOT as a leader in the field in roadside environmental management

8) Inter-agency buy-in on MoDOT Roadside Management Program.
9) Moves MoDOT toward completion of enterprise-wide GIS database.
10) Provides environmental database for assessing impacts caused by future changes in system.

Research or Evaluation Period: The estimated time period for the initial investigation is approximately one year. A report on the results is expected to be complete by December 31, 2002. This time frame allows for data collection throughout the growing season.

Potential Funding: MoDOT research funding.

Procedure: Natural prairie remnants present within MoDOT rights-of-way on Highway 36 between the junction of Route J in Ralls County, and the junction of Highway 151 in Clarence (approximately 36 miles) will serve as the test area for this research project. This area was selected based on observations by MoDOT Roadside personnel who have reported the presence of many native prairie grasses and forbs along this section of roadway. In addition, this roadway will be upgraded to four lane interstate status as funding becomes available. Therefore, an accurate database of the vegetation present in the area will be useful for estimating the impacts that construction will have upon this natural area.

Data collection will begin during June of 2001 at the eastern edge of this corridor and extend westward to the test area boundaries. Using the GPS receiver, the investigators will identify and record the species present within the sampling area. The entire right of way will be sampled and will be divided up into one hundred foot sections. The species present within each section will be recorded. Rare, uncommon, or species of special interest within each section will be recorded using exact coordinates. Data and observations about each species, such as relative abundance, identification of any disease or pest problems, seed production, noxious weed presence, etc. will be collected and recorded for future entry into the GIS. The researchers will devote the greatest amount of time to areas that exhibit the greatest amount of diversity of native vegetation. Obvious large expanses of fescue or other monoculture with very little diversity present will be recorded as such. It is expected that data collection will be completed by May of 2002.

During the winter months, data collection will focus primarily on woody and grass species that can be identified during this time of year.

After the completion of data collection, entry of the data into the GIS will allow for the production of spatially oriented maps of the vegetation present within the test corridor. These maps will be provided to personnel in Design/Environmental Studies and can be used to determine if any significant impacts to native vegetation are likely in the corridor. The maps will also be provided to Area Engineers, Maintenance Superintendents, and building supervisors so that mowing and spraying operations in the corridor can be tailored to increase efficiency, save money, and avoid any potential environmental impacts. The results will be made available in a report to other Roadside personnel throughout the state by December 31, 2002. Results may be made available to other agencies, such as the Missouri Department of Conservation at their request.

Staffing: The primary investigator, Chris Shulse (Roadside Manager, Northeast District), will be involved with data collection, data entry into the GIS, and map production. He is experienced with field identification of both native and non-native vegetation found in Northeast Missouri and has experience in the determination of wetland boundaries. He will devote approximately 20 % of his work schedule to this project.

A Roadside Management Intern, to be hired in May 2001, will devote approximately 75% of his/her time to the project. The intern will be responsible for most of the data collection during the summer, as well as some of the data entry and map production. We envision the intern returning in May 2002 to complete data collection and to help with map production.

Stacy Armstrong, Roadside Management Supervisor, will provide technical assistance with plant identification and distribution, as well as advice about department policy and procedure concerning vegetation management. Less than 1% of her work schedule will be devoted to this project.

Several MoDOT staff will allocate approximately 5% of their work schedule to provide technical assistance for this project as follows:
1) Gene Gardner (Senior Environmental Specialist, Design/Environmental Studies) will provide assistance in ArcView GIS applications and provide spatial data for analyses (e.g., digital orthophoto quarterquad coverage of District 3, streams, soils, public lands, wetlands, etc.). He will continue to conduct coordination with the Missouri Department of Conservation and U.S. Fish and Wildlife Service and will provide information on threatened, endangered, or otherwise sensitive species and their habitats (i.e., Heritage Database Information) within District 3. He will also provide logistical assistance in the collection of GPS data, assist in the assimilation, transfer and analysis of data, and provide input for reports on the overall results of this project.
2) Terri Wren (Senior Cartographer, Design/Environmental Studies) is an advanced ArcView GIS user and will provide technical support when necessary. She is also widely experienced with GPS field applications and keeps abreast of the most recent GPS technology. She will provide assistance in the collection of GPS data in the field upon initiation of this project and can provide limited assistance in the assimilation, transfer and analysis of data for GIS applications.
3) Wetland Specialists (Design/Environmental Studies) can provide assistance in the determination of wetland boundaries and can provide technical services such as the identification of plant species and communities whenever necessary.

Additional professional assistance is available through staff with the Missouri Department of Conservation:
1) Tim Smith (Botanist, Natural History Section) is located in Jefferson City and will provide technical assistance in the identification of plant species and communities

whenever necessary. Mr. Smith can also evaluate the effectiveness of any potential roadside management recommendations (e.g., haying, mowing, erosion control applications, etc.) that may be developed that would encourage or maintain native roadside vegetation.
2) Greg Gremaud (Regional Natural History Biologist, Natural History Section) is located in MDC's Northeast Regional Office in Kirksville, Missouri and has offered to provide technical assistance in the identification of plant species and communities whenever necessary. In addition, Mr. Gremaud is a recognized expert in the establishment of native vegetation in northern Missouri, particularly those methods that he developed to establish or restore native prairie on state and private lands (i.e., hydro-mulching applications using prairie hay).

Equipment (purchased):

GPS data logger and software		$10,000
Laptop Computer	$3200	
Workstation		$3500
CD Writer		$450
Zip Drive		$175
Digital Camera	$1000	
ArcView and License (2)	$1400	

(Department owned):

1997 Ford F-250XL HD (B4393) pickup for travel to and from field site.
Wide format printer (located in D3 Design)

Budget: Time dedicated to this project will come out of regular wages. No research funding will be used on time spent on this project. The requested funds will be used solely to purchase the following equipment for use on this project.

Trimble Pro-XR GPS w/TSC1 Data Logger and Pathfinder Office Software $10,005.45

ArcView 3.2a under MoDOT licensing on both laptop and workstation $1400.00

IBM Thinkpad T20 Laptop Computer $3,135.47

Compaq Professional Workstation, AP250 Minitower,
AP250 w/i820, 128R/9L2/128mb $2009.00
16/4 Token Ring PC Card $153.00
P110 Color Monitor $902.00
CarePaq Monitor Extensions 3 x 9 x 5 x 2 Business Day $60.00
Matrox Video Card $95.00

Hewlett Packard CD-Writer 9600se Rewritable SCSI HDSO CD Writer $303.63
2930U Kit SCSI PCI 1CH, CB Man EZ SCSI 95/98/NT $81.94
10 ft. SCSI 2 External Cable MD50M/MD50M $31.10

Iomega 250mb External Zip Drive $146.07

Kodak DC290 Digital Camera	$599.95
Compact Flash Card Reader model 8193542	$39.95
Accessory Kit w/10mb card and rechargeable battery set (1395185)	$99.95
Lens Kit w/camera and lens case (model 1574193)	$124.95
Paint Shop Pro. V7.0 Full Version	$85.91

TOTAL: $19,273.37

All costs are estimated based on the most current manufacturers prices. Costs may fluctuate and there may be some minor changes in hardware purchases. Therefore, an additional $726.63 is requested in order to cover any increase in pricing of the equipment. This brings the total cost of the project to **$20,000.00**.

Research Work Plan

Date: **December 12, 2002**

Project Number: **RI01-007 (expansion of project)**

Title: **Development and Implementation of Roadway Features Inventory**

Research Agency: MoDOT -- Maintenance Division personnel in both District 3 and General Headquarters, as well as Design/Environmental and Planning personnel at General Headquarters.

Principal Investigators: Chris Shulse, Roadside Manager – principal investigator
Steven "Butch" Mundle, MSII – principal investigator
Arnold Williams, Senior GIS Specialist – resource
Melissa Anderson, P.E., Senior Research, Development and Technology Assistant - resource

Objective: **1)** Establish process to inventory and map relevant roadway/maintenance features based on process now being established with RI01-007 (Environmental Roadside Inventory). **2)** Identify additional maintenance and environmental features to be included in a state-of-the-art GPS/GIS inventory of MoDOT roadways. **3)** Increase awareness and use of GPS/GIS at MoDOT. **4)** Investigate and pursue integration of roadway features data in to department's TMS system.

Background and Significance of Work: GPS and GIS are now successfully used in MoDOT environmental and roadside maintenance work. Environmental Studies personnel in Design at General Headquarters currently use GIS/GPS technology to map and integrate information about wetlands, endangered species, and cultural resources. The new injection herbicide spray units located in the districts also have GPS units on board which can be used to map areas of herbicide application and areas that are sensitive to these applications. The use of GIS/GPS technology to expand the inventory of roadside features (RI01-007) began in the summer of 2001. The results of this research to date have shown that this technology can be a useful tool to catalog and manage roadside environmental features.

After two field seasons, RI01-007 has resulted in approximately 50 acres of roadside prairie remnant being identified and mapped. Over 33,000 individual plants have been counted and mapped as either individuals or members of a population. We have identified dominant species present in each section of prairie remnant during June, July, and August of 2002. The study has also resulted in the discovery of additional locations

of a plant that is state listed as rare and included in the Missouri Department of Conservation's Heritage Database. This information will be provided to MDC. We have also discovered a naturally occurring hybrid between two species of gentian, a prairie wildflower, that has not been recorded in the state of Missouri. The locations of the hybrid, as well as the parent species have been recorded and mapped and were the subject of a separate research project by a student at Culver-Stockton College in Canton, MO. Two species of noxious weeds were also identified and mapped in the study corridor and work is currently underway to transfer this data to the onboard computer system of an injection sprayer. Once transferred, we will test the ability of the sprayer to alert the operator of the locations of these weeds. Data collected thus far provide an excellent baseline to assess how our vegetation management practices affect both desirable prairie species as well as noxious weeds. In order for these assessments to be made, data collection must continue and these additional data added to the GIS.

In addition to the continuation of environmental roadside features data collection for RI01-007, we would like to expand the scope of the inventory to include other features within the study corridor. Some of these features are environmental in nature (wetlands, ponds, streams, etc.) while others would be "maintenance features." This would include signs, culverts, pipes, guardrail, and other assets. Additionally, maintenance concerns such as erosion problems, pavement condition, striping condition, etc. would be mapped and recorded. We will also investigate ways to pursue integration of these data into the TMS system.

The use of GIS/GPS technology in the field operations at MoDOT can be a very powerful and very effective tool for enhancing the overall effectiveness of our workforce. Use of this tool in field operations will allow for better management decision-making. Establishing these inventories also demonstrates to other agencies and the public MoDOT's commitment to saving money and environmental stewardship.

Action Plan:

Step 1 – Form team of Principal Investigators and develop procedure (complete).
Step 2 – Obtain funding for project.
Step 3 – Obtain equipment (GPS unit).
Step 4 – Collect data.
Step 5 – Compile and analyze data.
Step 6 – Investigate ways to incorporate data into TMS.
Step 7 - Report results.
Step 8 – Provide model of adoption for other districts to roadway features inventories.

Literature Search: Data management and reporting will increase in the near future. By giving data a spatial reference, each piece of information is provided with a context and therefore a new method of analysis. GIS provides "proximity analysis" which in turn provides answers to geographically complex questions in a way that can easily be used. "In providing once esoteric or cryptic information with a visual explanation, technological expertise among system users fades as an issue" (Steele, 2000). GPS is often used to fill in information gaps and once a GIS is in place, it remains a tool for data maintenance and enhancement.

The city of Everett, Washington's Public Works Department has integrated its databases into a central management system that incorporates GIS technology. The result has been better project tracking and asset management saving taxpayers money (Brandley, 2001).

Camden County, New Jersey uses a GIS-based asset management system to keep track of its roadway signage and signals. The system allows the county to track the history, maintenance, inventory, and

management of signs and signals. The system can also be used for other infrastructure items such as roadways, pavement segments, bridges, lights, and water and sewer components. The GIS has provided the county with timely and accurate information to support decision-making (Noe, 2000).

In Florida, researchers at the University of Florida have been using GIS to identify landscape features that could be incorporated into an ecological greenways network (Carr et al. 1998). In coordination with the Florida DOT, Florida Game and Fresh Water Fish Commission, and Florida Natural Areas Inventory, natural areas and wildlife sites were identified and a plan was developed for protection and linkage of significant natural landscapes, which included roadside management.

When considering the social and economic impacts to communities as a result of transportation facility development, the Federal Highway Administration has stated that the aesthetic qualities of streets and roads are often more important to the qualities of their surroundings than are the aesthetic qualities of the properties to which they provide access. There is a growing concern among professionals and citizens that in designing roads we have increasingly, and unnecessarily, neglected aesthetics and other community values (Passonneau 1996).

Highways have long been considered to have an adverse impact on wildlife, but until recently very little work has been completed to determine how to minimize these impacts. A major management objective for the Washington State Department of Transportation developed some partnering studies to identify significant wildlife travel corridors and maintain habitat connectivity through appropriate roadside vegetation management (Wagner et al. 1998). Identifying areas where native vegetation currently provides habitat and ensuring connectivity of these grassland habitats by managing Missouri roadsides could make a cost-effective contribution and facilitate the goals of a number of state and federal agencies in Missouri.

Various utility companies throughout the country are beginning to create spatially oriented databases with information about the vegetation within their corridors. The information gathered is integrated with local government, utility asset, and other environmental data including National Heritage and Endangered Species Program. The maps are used by utility company decision makers, including field personnel, when applying herbicides, removing unwanted vegetation, or other operations that can impact wildlife and the environment (ESRI Press Release 3/2000 www.esri.com).

Other agencies, both governmental and private, are using GIS applications to manage vegetation. The U.S. Forest Service is using spatially oriented vegetation maps of public lands to locate optimal habitat for threatened and endangered species. The World Resources Institute (WRI) uses GIS data and maps to study worldwide deforestation and to identify the threats to frontier forests (Lang, 2000). The concepts developed by WRI can be applied on a regional level when looking at stands of native vegetation on roadsides, and identifying threats to their survival.

Spatially oriented databases have proven to be useful tools to manage resources in both the biological and the man-made environments. Whether keeping track of endangered species, vegetation, road signs, or guardrail, connecting spatial orientation to information about a feature can mean more efficient management of resources. This research study has taken the first steps to creating a means to efficiently catalog and manage roadside environmental features. In continuing with this research, not only will we be continuing the mapping of environmental features and building upon the roadside environmental features database, we will be expanding the scope of the project to include the man-made roadway assets in a spatially oriented database. In the process, we will be finding ways for districts to access this information quickly and efficiently and in greater detail that has previously been possible.

Brandley, Jim. 2001. Public works department merges data into a central management system. Kirchner, J.R. (ed.) Public Works magazine. 132(3):22-24.

Carr, M. H., P. D. Awick, T. Hoctor, W. Harrell, A Goethals, and M. Benedict. 1998. Using GIS for identifying the interface between ecological greenways and roadway systems at the state and sub-state scales. Pages 68-69 *In* G. L. Evink, P. A. Garrett, D. Zeigler, and J. Berry, eds., Proceedings of the International

Conference on Wildlife Ecology and Transportation. Fort Myers, Florida, February 10-12, 1998. 263pp.

Lang, Laura. 2000. Managing Natural Resources with GIS. ESRI Press.

Noe, Curt. 2000. GIS-based life cycle management of highway assets. Kirchner, J.R. (ed.) Public Works magazine. 131(9):30-34.

Passonneau, Joseph. 1996. In the design of roads: aesthetics and other community values. Transportation Research Board 75th Annual Meeting, January 7-11, 1996. (abstract)

Steele, Sharon. 2000. GIS and public works: toward smarter government. Kirchner, J.R. (ed.) Public Works magazine 131(6):16-18.

Wagner, P., M. Carey, and J. Lehmkukl. 1998. Assessing habitat connectivity through transportation corridors on a broad scale: an interagency approach. Pages 66-67 *In* G. L. Evink, P. A. Garrett, D. Zeigler, and J. Berry, eds., Proceedings of the International Conference on Wildlife Ecology and Transportation. Fort Myers, Florida, February 10-12, 1998. 263pp.

The following resources can be used for further information about the use of GIS and GPS :

Proceedings of the International Conference on Ecology and Transportation
National Roadside Vegetation Management Association Annual Convention Minutes
ESRI website (www.esri.com)

Method of Implementation: As the investigation proceeds, the developing GIS database will be consulted in developing management strategies for roadway features and roadside sections. The investigators will consult with Planning staff at GHQ during the investigation in order to ensure that the methods used and data collected will be compatible with, and can be integrated into, TMS.

Research results will aid in the adoption of GPS and GIS technologies at MoDOT. The process and features identified with this project will be formalized into a training manual and session for MoDOT Roadway and Maintenance Managers, Design and Environmental personnel**.** The results of the project will then be used to: 1) Increase the level of cost efficiencies through road and roadside management, 2) Used by Design and Environmental staff to plan and design travelway improvements, 3) Used during the environmental clearance process to expedite environmental constraint identification and mitigation needs, 4) incorporated into MoDOT asset management framework in order to more completely identify assets.

Anticipated Benefits:

A) Provides data and direction for Roadside Management system

11) Accurate management of herbicide applications saving cost and labor.
12) Increased efficiency of mowing operations results in cost and labor savings.
13) Frees up labor normally spent on mowing and spraying for use on other tasks.
14) Identification of areas for collection of native grass and wildflower seed.
15) Identification of areas with erosion, noxious weed, or other maintenance problems.
16) Increased safety to the public and employees due to more efficient mowing and spraying operations that result in less exposure to chemicals and equipment.
17) Increase in public's perception of aesthetically pleasing, environmentally sound roadsides ("Total Driving Experience").

B) Establishes MoDOT as a leader in the field in roadside environmental management

18) Inter-agency buy-in on MoDOT Roadside Management Program.
19) Moves MoDOT toward completion of enterprise-wide GIS database.
20) Provides environmental database for assessing impacts caused by future changes in system.

C) Showcases MoDOT's commitment to asset management and maintenance

21) Incorporates roadway assets into an easy to access spatially-oriented database.
22) Provides transportation managers with a powerful tool to track and maintain MoDOT roadway assets.
23) Increased efficiency of asset management.
24) Increased safety for motorists.

Research or Evaluation Period: The estimated time period for data collection of roadway features and creation of the GIS database is one year. The investigation would begin in May 2003. The environmental roadside features inventory will also continue during the summers of 2003 and 2004.

Potential Funding: MoDOT research funding.

Procedure: The study corridor for the roadway features inventory will be the same as that of RI01-007. This is a 36 - mile stretch of highway from just east of Monroe City west to Clarence. The following maintenance features within the corridor will be mapped: signs, guardrail, culverts, and pipes. In addition to location, other data collected will include condition of these structures. Historical information obtained from Design RAG maps will be added to the GIS. Additionally, video files from the ARAN vehicle will be added to the GIS for each segment of roadway. Old design plans can also be scanned into a digital image format and linked to the database.

Procedures for mapping and creation of databases related to environmental roadside features will remain the same. Plant species already mapped will be remapped to investigate how our vegetation management practices over one growing season have affected certain species. Additional species will be mapped and added to the database.

Staffing: The primary investigator, Chris Shulse (Roadside Manager, Northeast District), will be involved with data collection, data entry into the GIS, and map production. As principal investigator on the RI01-007 project, he is experienced with the use of GIS and GPS technology. He will devote approximately 20 % of his work schedule to this project.

Steven "Butch" Mundle (Maintenance Superintendent II, Northeast District) will be involved in determining what information is collected in the field and the creation of datasets within the GIS. He has nearly 30 years of maintenance experience with MoDOT as well as experience with asset management using TMS. Butch will devote approximately 10% of his work schedule to this project.

Ashli Houchins, Roadside Management Intern during the summers of 2001 and 2002, will be hired as a temporary employee for the summer of 2003 to map the maintenance features as well as integrate the data into the GIS. As an intern, Ashli served as the primary data collector for RI01-007 and has many hours of experience using GPS in the field and creation of databases in a GIS. In addition the working on the roadway features inventory, Ashli will help to train a new intern to take over data collection for the environmental component of RI01-007. Ashli will devote 100% of her time to this project.

A Roadside Management Intern, to be hired in May 2003, will devote 100% of his/her time to continuing the environmental features work of RI01-007. The intern will be responsible for most of the data collection during the summer, as well as some of the data entry and map production. We envision the intern returning in May 2004 to continue data collection and to help with map production.

Arnold Williams, Senior GIS Specialist at GHQ, will provide technical assistance and support when necessary. Arnold is an advanced ArcView user and is experienced with the use of GPS technology in the field. Less than 5% of his work schedule will be dedicated to this project.

Melissa Anderson, P.E., Senior Research, Development and Technology Assistant, will provide assistance and support when necessary on issues relating to TMS. Melissa has experience using the TMS database and can provide guidance on issues relating to system compatibility.

Equipment (purchased):

GPS data logger and software $10,000

(Department owned):

1997 Ford F-250XL HD (B4393) pickup for travel to and from field site.
Wide format printer (located in D3 Design)
The equipment purchased for RI01-007 in 2001 will continue to be used for the environmental features portion of the study, and will also be used for the roadway features inventory. However, a second GPS unit is needed in order to quickly and efficiently catalog both environmental features and roadway features. The availability of the second unit will also allow for a greater amount of data to be collected within the prairie remnants during the field season.

Budget:

Trimble Pro-XR GPS w/TSC1 Data Logger and Pathfinder Office Software $10,005.45

Wages for one Temporary Employee from mid-May 2003 until mid-August, 2003
480 hours @ $10.81 per hour = $5,188.80

Wages for one Roadside Management Intern from mid-May 2003 until mid-August, 2003
480 hours @ $8.70 per hour = $4,176.00

TOTAL: $19,370.25

Appendix B: Presentations and Articles

July 2001 – Roadside Management and GIS. Presentation by Chris Shulse and Terri Wren to MoDOT State Design Engineer promoting the concept of the project.

July 11, 2001 - Roadside Care Goes High Tech. Hannibal Courier-Post newspaper article featuring the environmental roadside inventory project.

2001 - Development of an Environmental Roadside Inventory Using Spatially Oriented Databases. Research, Development, and Technology Summary Report FY 2001.

June 23-27, 2002 - Using Spatially Oriented Databases as a Tool to Manage Roadside Prairie Remnants. Presentation at the 18th North American Prairie Conference, Kirksville, Missouri.

Fall 2002 – Update on District 3 GIS Research. Presentation at statewide meeting of roadside management staff.

December 2002 – Presentation of the project to RDT staff in Jefferson City.

December 13, 2002 – Hybridization of *Gentiana* in the Tallgrass Prairie. Senior research project paper and presentation to students and faculty of Culver-Stockton College by Ashli Houchins, Roadside Management Intern.

2003 - Missouri's New Find. Greener Roadsides (vol. 10, no. 1, Spring 2003), Federal Highway Administration Newsletter, Washington, D.C.

2003 - Reaching Toward the Sky for Asset Management. Research, Development, and Technology Quarterly (vol. 6, no. 4).

March 18-20, 2003 - Managing Roadside Vegetation Using GPS and GIS. Presentation at the 93rd Annual Conference of the Highway Engineers' Association of Missouri, Branson, Missouri.

March 24-26, 2003 - Roadside Vegetation Management Using GPS and GIS Technology. Presentation at the 8th Annual Missouri 2003 GIS Conference, Columbia, Missouri.

April 2003 – Hybridization of *Gentiana* in the Tallgrass Prairie. Presentation at Missouri Academy of Sciences annual meeting by Ashli Houchins, Roadside Management Intern.

2003 - Shulse, C., A. Houchins, T. Wren, and S. Armstrong. Using Spatially Oriented Databases as a Tool to Manage Roadside Prairie Remnants. pp. 111-115. In: "Proceedings of the 18th North American Prairie Conference 'Promoting Prairie'", Fore, S. editor, Truman State University Press, Kirksville, Missouri.

December 2003 – GPS Project Summary for 2003. Presentation at statewide meeting of roadside management staff.

January 2004 – Development and Implementation of an Environmental Roadside Inventory. Interim Status Report RI01-007 for Research, Development, and Technology.

September 2004 – GPS Project Summary for 2003 and update on progress with GPS-equipped herbicide sprayers. Presentation at statewide meeting of roadside management staff.

Appendix C: Hybridization of *Gentiana* in the Tallgrass Prairie

Following is the senior research paper submitted by Ashli Houchins, Roadside Management Intern during 2001, 2002, and seasonal employee in Roadside Operations during 2003, to satisfy the degree requirements of Bachelor of Science in Biology at Culver-Stockton College in Canton, Missouri. In late 2001, two species of *Gentiana*, a native prairie forb, were discovered at a location within the Route 36 Corridor. In addition to the two species, it appeared that either a third un-identified species or hybrid was present at the site. Ashli decided to use GPS/GIS technology, along with a traditional taxonomic study, to research the gentian complex in the study corridor.

Hybridization of *Gentiana* in the Tallgrass Prairie

Ashli Houchins

Culver-Stockton College

Senior Research

December 13, 2002

Abstract

The purpose of this study was to determine if the prairie wildflowers downy gentian (*Gentiana puberulenta*) and closed gentian (*G. andrewsii*) are able to naturally hybridize. The possibility of hybridization arose following the observation of possible hybrid gentians in 2001. Methods utilized in this study include the observation and documentation of flowering phenology, the mapping of distribution for each species, and the analysis of morphological data. It was discovered that the blooming seasons of downy and closed gentians overlap and that the distribution of the two species are separate with possible hybrids located in both areas. The analysis of morphological data illustrated that the possible hybrid has physical characteristics similar to both downy gentian and closed gentian. The determining factor involved the measurement of the possible hybrid flower corolla lobes and pleats. Four of the six possible hybrid gentians presented corolla lobes longer than the pleats, indicating they are, in fact, hybrids. The conclusion obtained from this study is that downy and closed gentians are involved in cross breeding and that they do naturally hybridize.

Hybridization of *Gentiana* in the Tallgrass Prairie

Introduction

Tallgrass prairies once dominated the Midwest, stretching from the Gulf of Mexico into Canada, extending from the edge of the Rocky Mountains east through Illinois. Evidence shows that these prairies expanded greatly as the last glaciers retreated from the Midwest, some 8,000 years ago. The climate from this time to 3,000 years ago was hotter and drier than now, which favored the development of grasslands and the retreat of woodlands (Ladd 1995).

Prior to settlement the northern half and western side of the state of Missouri were partially to fully covered in prairie (CARES, 2002). To be considered a tallgrass prairie, the following characteristics must appear:

> [A]n abundance of grasses that typically grow three or more feet tall, including Big and Little Bluestem grasses, Gama Grass, Indian Grass, Switch Grass, and Prairie Cord Grass. Shorter grasses and sedges are common, as are a rich assortment of flowering plants (Ladd 1995).

Two tallgrass prairie wildflowers, downy gentian, *Gentiana puberulenta*, (Figure1) and closed gentian, also known as Bottle gentian, *G. andrewsii* var. *dakotica*, (Figure 2) are being studied in this project. These perennial dicots are native to the United States and belong to the family Gentianaceae (USDA, NRCS, 2002). Observations from a floristic study conducted in 2001 suggest the possibility of hybridization between the aforementioned gentian species.

Figure 1. Downy Gentian

Figure 2. Closed Gentian

A hybrid is defined as “the offspring of genetically dissimilar parents” (Purves et al. 2001). Hybridization occurs between taxonomic neighbors such as horses and donkeys or lions and tigers, species that are members of the same genus or family (Schilthuizen 2002). While hybridization often results in mortality, it is possible for hybridization to create new species. Examples of naturally occurring hybrids are the mule, with a horse mother and donkey father, and the sunflower *Helianthus anomalus*, a mixture of *H. annuus* and *H. petiolaris* (Schilthuizen 2002).

Through collection and analysis of data on downy and closed gentians, it may be determined if the two species are capable of naturally hybridizing. By studying and comparing the physical characteristics of the possible hybrid to those of the two common species, conclusions will be made as to whether or not the plant could actually be a hybrid. Identifying a new species of gentian would be a significant discovery to the prairie community.

Materials and Methods

The study site is located at the junction of Highway 36 and Route J, Ralls County, Missouri, approximately two miles east of Monroe City. The site is on the south side of the roadway, between Highway 36 and a railroad track. This tract is a fairly large prairie remnant that presents extreme diversity in the plant life it supports. Numerous native prairie plants, both grasses and forbs, are found in this area throughout the year.

Several techniques were utilized in the collection of data, including analysis of the morphology, phenology, biogeography, and phylogeny of the gentians. First, flowering phenology was observed and documented. Plant locations were recorded using a Global Positioning System (GPS) unit on Monday, September 30, 2002 and Thursday, October 3, 2002. The locations appear as Universal Trans Mercator (UTM) coordinates and have been transferred onto an ArcView spatial map (see Figure 4). Plotting locations of the downy, closed, and possible hybrid gentians provide distance, location, and distribution information.

Morphological characteristics from a sample of each species were observed, measured, and documented on Friday and Saturday, October 11 and 12, 2002. All significant physical details of the flowers, leaves, stems, roots, and overall plants were measured and recorded. These details include measurements of length, height, and width of the plants, leaves, and stems, along with observations of number, color, and shape of flowers, leaves, and plants.

Results

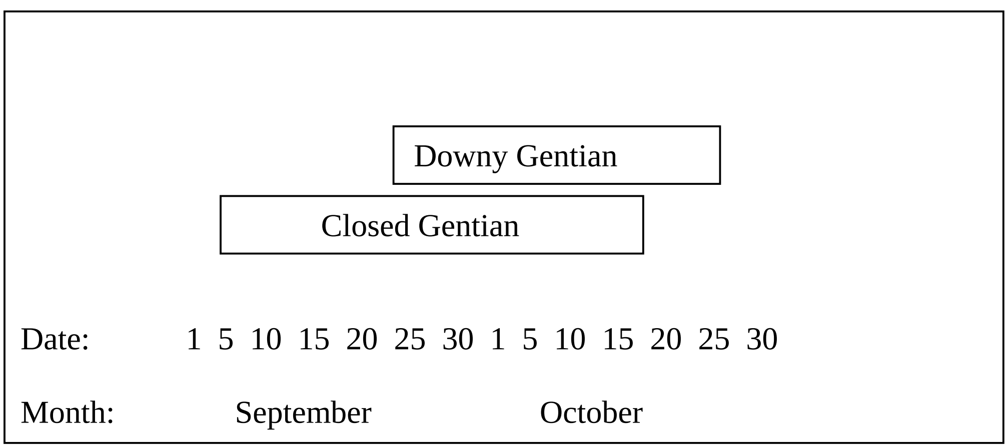

Figure 3. Timeline showing overlap in blooming seasons

As shown in Figure 3, the closed gentians began blooming a little over two weeks before the downy gentians, and all plants were in full bloom by September 24. The species were in bloom together from September 24 to around October 20.

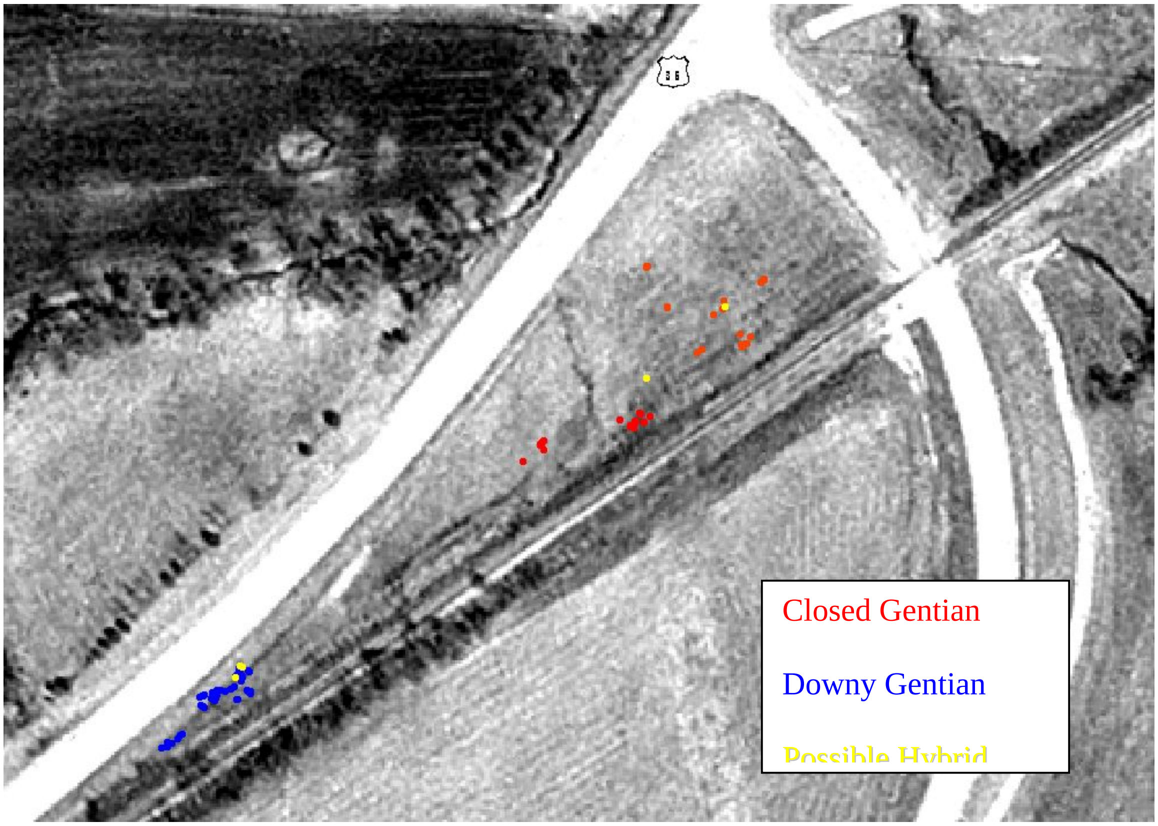

Figure 4. Spatial map showing locations and distribution of downy, closed, and possible hybrid gentians

Figure 4 presents location and distribution information of downy, closed, and possible hybrid gentians through a spatial map. As seen, the closed gentians were located mainly in the Southeast area of the study site (right in the map). The downy gentians were separate from the closed and located in the West area of the study site (lower left in the map). A fairly large distance separated these two species and as shown, possible hybrids were found in both areas.

Table 1. Comparison of overall plant characteristics from downy, closed, and possible hybrid gentians

	Downy	Closed	Hybrid
Height (cm)	43.67 ± 1.24	50.62 ± 2.75	55.72 ± 5.25
Flower Number	6	13	8
Flower Opens	Yes	No	No or Slight

Table 2. Comparison of flowers from downy, closed, and possible hybrid gentians

	Downy	Closed	Hybrid
Petal Length (cm)	3.66 ± 0.08	3.30 ± 0.06	3.32 ± 0.10
Petal Number	5	5	5
Petal Tip Shape	Point	Round	5 point, 1 rounded point
Between Petal Shape	Point	Round	Point
Ovary Length (cm)	2.05 ± 0.04	2.47 ± 0.07	2.66 ± 0.10
Ovary Diameter (cm)	0.50 ± 0.02	0.50 ± 0.04	0.61 ± 0.13
Stamen Length (cm)	1.81 ± 0.06	2.02 ± 0.04	1.62 ± 0.05
Color	Dark	Light	Dark

Table 3. Comparison of leaves from downy, closed, and possible hybrid gentians

	Downy	Closed	Hybrid
Length (cm)	2.59-4.81	5.03-7.85	4.75-6.42
Width (cm)	0.62-1.02	1.41-2.49	0.95-1.47
Shape	Oblong	Oblong	Oblong
Vein Pattern	Parallel	Parallel	Parallel
Orientation	Opposite	Opposite	Opposite
Hairy	No	No	No
Edges	Smooth	Smooth	Smooth

Table 4. Comparison of stems from downy, closed, and possible hybrid gentians

	Downy	Closed	Hybrid
Shape	Round	Round	Round
Hairy	No	No	No
Diameter (cm)	0.16 ± 0.01	0.29 ± 0.01	0.23 ± 0.04

Tables 1 through 4 present the morphological data collected from samples at the study site. Standard error of means are present where necessary. Sample sizes of the gentians were downy 18, closed 21, and hybrid 6. All measurements are the means from the samples. As shown, the possible hybrids possess morphological characteristics similar to both downy and closed gentians. For example, the possible hybrids are more similar to closed gentians in plant height, petal length, and leaf length. However, they are more similar to downy gentians in petal shape, petal color, and flower number.

In some instances, the morphological characteristics of the possible hybrids are intermediates of the downy and closed gentians, while other characteristics exceed those of the two species. Characteristics in which the possible hybrids are intermediate include flower number, flower opening, petal length, stamen length, leaf length, leaf width, and stem diameter. The possible hybrids exceed downy and closed gentian in plant height, ovary length, and ovary diameter--three important diagnostic features, two of which are involved in reproduction. These characteristics strongly support the possibility that hybrid vigor is occurring.

The possible hybrids resemble closed gentians in one important way: their flowers do not open or may open only slightly. This plays an important role when identifying a possible hybrid in the field--the darker flower color makes downy the obvious choice, while the petals not opening make closed the better identification. It is this discrepancy that leads to the possibility of a hybrid.

Table 5. Corolla lobe and pleat lengths for downy, closed, and possible hybrid gentians

Gentian	Corolla Lobe Length (cm)	Pleat Length (cm)
Downy	3.70	2.92
Closed 1	3.85	4.00
Closed 2	3.20	3.20
Hybrid 1	3.69	3.20
Hybrid 2	3.10	3.10
Hybrid 3	3.00	3.00
Hybrid 4	2.20	2.00
Hybrid 5	3.50	3.10
Hybrid 6	3.40	3.20

Dried and pressed specimens were used to measure flower characteristics involving the corolla lobes and the pleats. Six possible hybrid plants, one downy, and two closed were available for this measurement. In downy gentians, lobes are longer than pleats and in closed gentians, lobes and pleats are close to the same length (see Figures 5 and 6). Yatskievych (personal communication) relayed that the determining factor for whether a plant is a cross between downy and closed gentians is if its corolla lobes are longer than the fringed margins of the pleats between the lobes. As Table 5 shows, four of the six possible hybrids (numbers 1, 4, 5, and 6) present this feature.

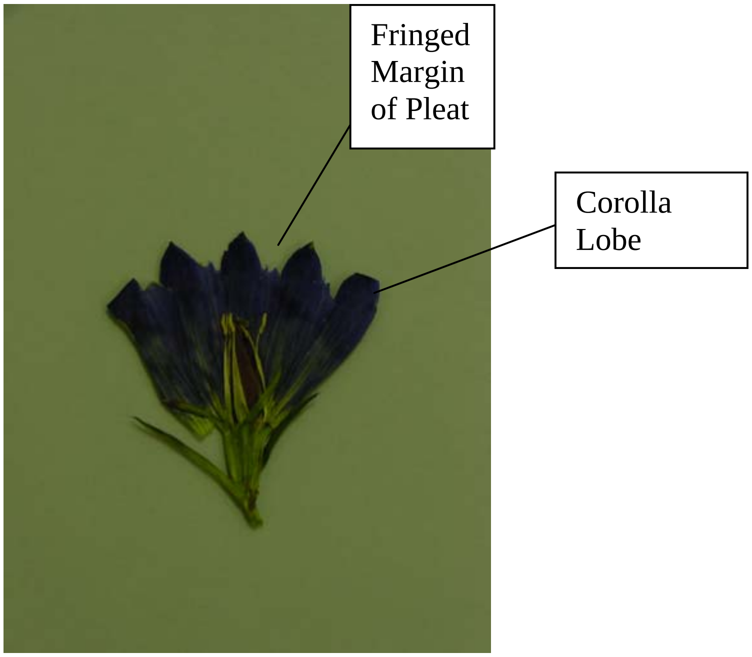

Figure 5. Downy Gentian Flower

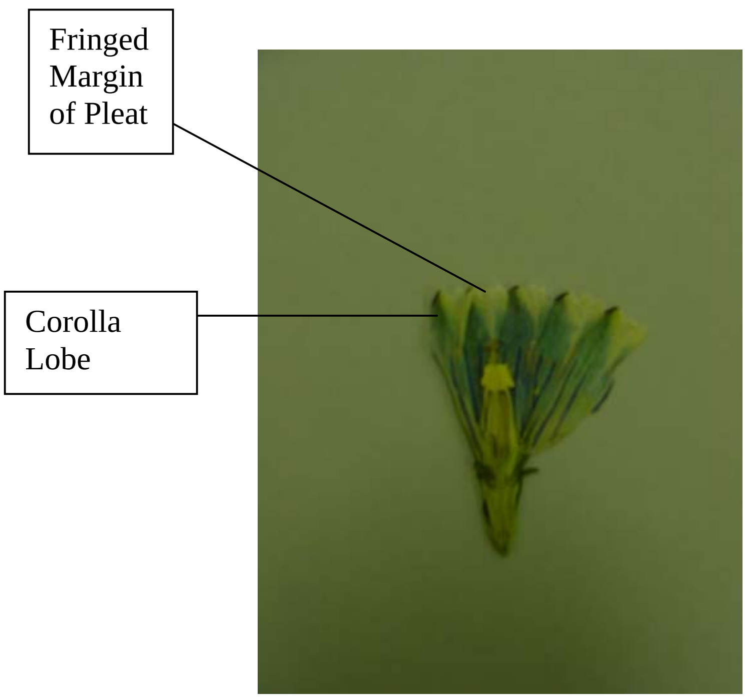

Figure 6. Closed Gentian Flower

Figure 7. Hybrid 1 Flower

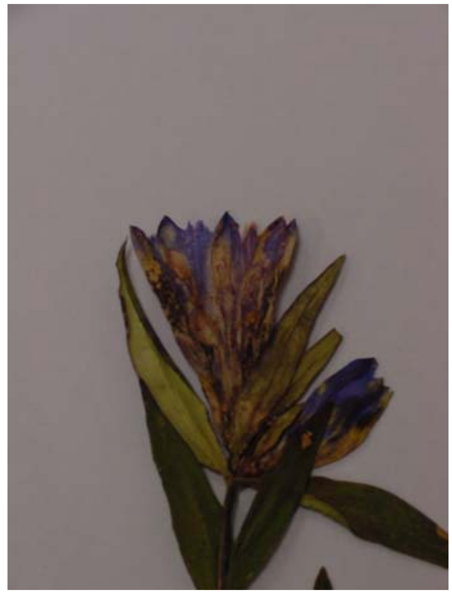

Figure 8. Hybrid 4 Flower

Figure 9. Hybrid 5 Flower

Figure 10. Hybrid 6 Flower

As seen in Figures 7 through 10, the corolla lobes on the hybrid flower are longer than the fringed margins of the pleats. Also obvious is the darker color of the flowers, except for that in Figure 9, which faded dramatically during pressing.

Discussion

The overlapping blooming seasons of downy and closed gentians indicates first of all, that natural hybridization *is* possible. The analysis of morphological features demonstrates the similarities between downy and possible hybrid gentians and closed and possible hybrid gentians. However, this alone does not contribute enough significant information to declare that hybridization occurs within *Gentiana*.

The deciding factor in determining if hybridization has occurred is to measure corolla lobe and pleat lengths. In a hybrid between downy and closed gentians (actually between closed and any other gentian), the corolla lobes should be longer than the fringed margins of the pleats between the lobes. Combining this information with other morphological features allows for a more complete determination of hybridization.

It was discovered while doing this project that research has been performed on hybridization in *Gentiana*, but most of this was conducted in Wisconsin. The hybrid between *G. puberulenta* and *G. andrewsii*, while nowhere common, has actually been identified in Iowa, Illinois, Ohio, Minnesota, Wisconsin, and Ontario but has not been reported in Missouri. The hybrid has been called *G. x billingtonii* in some literature but this is not a validly published name.

Pringle (personal communication) confirmed through pictures that possible hybrids from the fall of 2001 were a cross between *G. puberulenta* and *G. andrewsii*. These plants were found and photographed at the study site in September of 2001 (see Figures 11 and 12). It is therefore known that hybridization *does* occur between the two species and at the Junction J and Route 36 study site. Yatskievych (personal communication) relayed that the pictures of possible hybrids from 2002 were not clear or detailed enough to determine if they were hybrids.

From measuring and analyzing the corolla lobe and pleat lengths of the six possible hybrids collected from the study site and pressed, four of the six were confirmed as crosses of *G. andrewsii* and *G. puberulenta* (see Figures 7 through 10). The two possible hybrids that are not actually hybrids are closed gentians, determined from the fact that the lengths of the corolla lobes and pleats are equal. By comparing data concerning flowering phenology, geography, and morphology, it was determined in this study that natural hybridization does occur between the *Gentiana* species of *puberulenta* and *andrewsii*.

Acknowledgements

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References

CARES. 2002. Map room (www.cares.missouri.edu). University of Missouri Social Sciences Unit, Columbia, MO 65201 USA.

Ladd, D. 1995. Tallgrass prairie wildflowers. Falcon Press Publishing Company, Helena, Montana. 262 pp.

Purves, W.K., D. Sadava, G.H. Orians, and H.C. Heller. 2001. Life: the science of biology. Sinauer Associates, Inc., Sunderland, Massachusetts. 1044 pp.

Schilthuizen, M. 2002. Caution: species crossing. Natural History 111:62-71.

USDA, NRCS. 2002. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

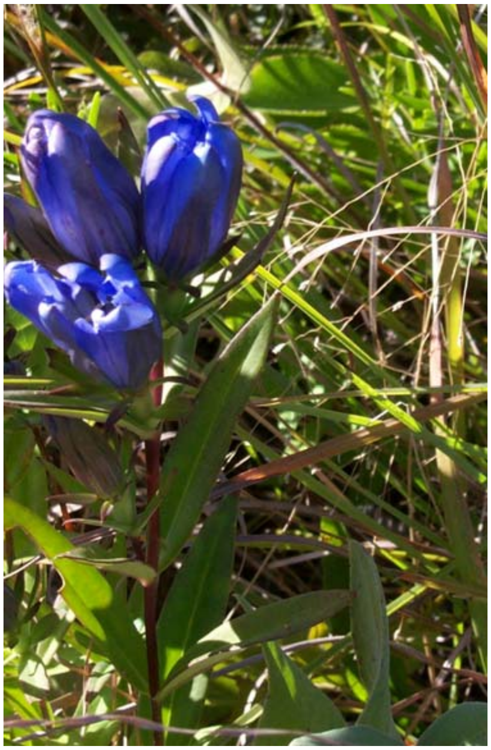


Figure 11. Hybrid Gentian from 2001

Figure 12. Hybrid Gentian from 2001

Appendix D: Selected Photographs Taken During Project

Compass Plant – Route 36

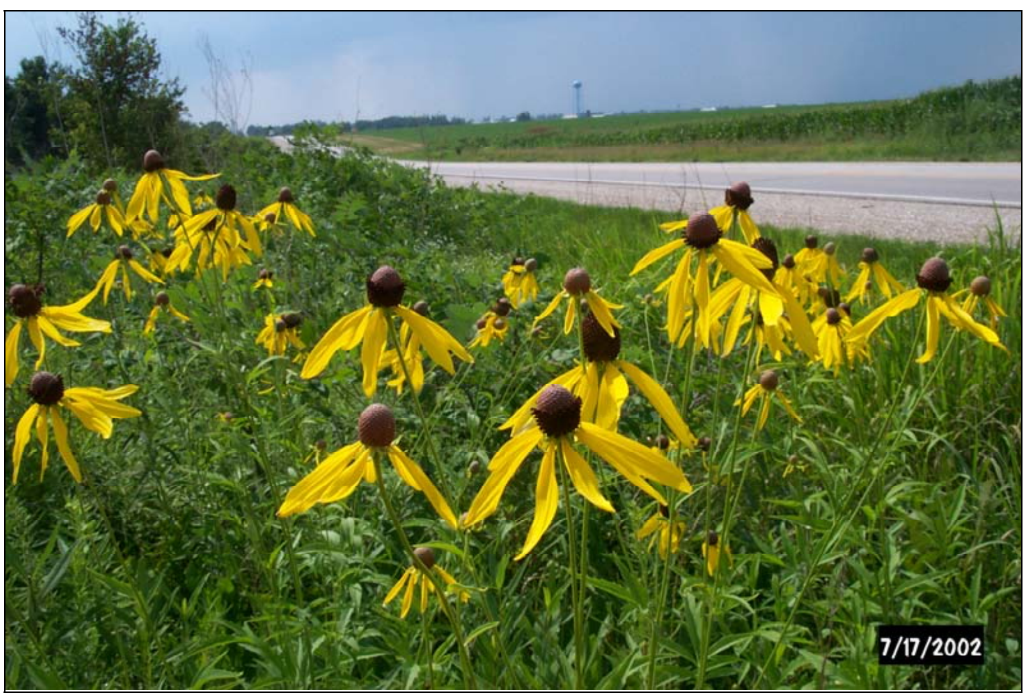
Downy Gentian – Route 36

Hoary Puccoon – Route 36

Spiderwort – Route 36

Spiderwort – Route 36

Sensitive Briar – Route 36



Gray Headed Coneflower – Route 36

Prairie Hyacinth – Route 36

Showy Goldenrod – Route 36

Pale Purple Coneflower and Giant Swallowtail Butterfly – Route Z Lincoln County

Prairie Rose – Route 36

Rose Hips (Fruit of Prairie Rose) - Route 36

Pale Purple Coneflower – Route Z Lincoln County

Aromatic Aster – Route Z Lincoln County

Closed Gentian – Route 36

Hybrid Gentian – Route 36

Downy Gentian and Sky Blue Aster – Route 54

Downy Gentian – Route 54

Thanks for all the hard work Ashli!

Thanks for all the hard work Ginnie!